Summary of Morehead City Harbor Section 111 Study
And
Status Report on Other Projects Related to Beach Erosion
At
Bogue Banks

EXECUTIVE SUMMARY

PURPOSE: The purpose of this study is to investigate the potential impacts of the Morehead City Harbor Federal navigation project on adjacent shorelines, in particular the ocean shoreline along Pine Knoll Shores. The study was conducted under the continuing authority of Section 111 of Public Law 90-483, as amended by Section 915 (f) and 940 of Public Law 99-662. Section 111 authority is limited to correcting damages to shorelines that can be directly attributed to Federal navigation projects. The primary study area for this report includes the Morehead City Harbor navigation project and the ocean shorelines along Bogue Banks and Shackleford Banks. The Bogue Banks study area extends from the east end of Fort Macon 25.4 miles west to Bogue Inlet. The Shackleford Banks study area extends from Beaufort Inlet 8.7 miles east to Barden Inlet.

LOCATION: Morehead City Harbor is located on the mid-eastern North Carolina coast between Bogue Banks to the west and Shackleford Banks to the east. The navigation project presently involves maintaining a 47-foot deep mean low water (mlw) by 450-foot wide ocean entrance channel through the ocean bar of Beaufort Inlet, which connects with channels and an inner harbor 45 deep at mlw. The North Carolina State Ports Authority operates the State Port facility at Morehead City Harbor. Morehead City is located adjacent to the Port facility and Beaufort is located in close proximity.

Bogue Banks is a south-facing, coastal barrier island that is approximately 25.4 miles long and is bordered on the east by Beaufort Inlet and on the west by Bogue Inlet. From east to west, Bogue Banks consists of Fort Macon State Park (1.4 miles of ocean shoreline) and the communities of Atlantic Beach (4.7 miles of ocean shoreline), Pine Knoll Shores (4.5 miles of ocean shoreline), Indian Beach and Salter Path (2.5 miles of ocean shoreline), and Emerald Isle Beach (12.3 miles of ocean shoreline).

Shackleford Banks is also a south-facing, coastal barrier island that is approximately 8.7 miles long and is bordered on the west by Beaufort Inlet and on the east by Barden Inlet and Cape Lookout. Shackleford Banks is part of the Cape Lookout National Seashore.

BACKGROUND: In August 1994, the Town of Pine Knoll Shores contacted the Wilmington District, US Army Corps of Engineers, with concerns over a perceived increase in the rate of erosion along its ocean shoreline. The Town of Pine Knoll Shores is an ocean front community with a 4.5 mile-long ocean shoreline that begins 6.1 miles west of Beaufort Inlet. The Town officials contended that their shoreline began to experience accelerated erosion immediately following the 1994 deepening of the Morehead City Harbor project from 40-feet mlw to 45-feet mlw.

During the 1994 deepening of the project, some of the dredged material was deposited on the shoreline fronting the Town of Atlantic Beach, located to the east of Pine Knoll Shores. The disposal of this material on the beach, which abruptly terminated near the east town limits of Pine Knoll Shores due to availability of the dredged material, created a wide offset in the alignment of the beach between Atlantic Beach and Pine Knoll Shores and was perceived by the town officials and local residents as causing increased erosion. As a result, the Town of Pine Knoll Shores requested that the Corps of Engineers conduct a study to determine if there was an increased erosion rate related to the operation and maintenance of the Morehead City Harbor navigation project. The Wilmington District initiated this study in February 1997 in partnership with the North Carolina Department of Environment and Natural Resources (DENR). DENR is the sponsor of the Morehead City Harbor navigation project and cost shared on the Section 111 study.

The Towns of Bogue Banks have also expressed a desire to have the Morehead City Harbor dredged maintenance material placed on their beaches rather than placed in the various disposal sites now being utilized.

STUDY: The Section 111 authority is limited to mitigating damages to shorelines that can be directly attributed to Federal navigation projects. Accordingly, the focus of this study was on the evaluation of changes in shoreline behavior on both Bogue Banks and Shackleford Banks that occurred following the implementation of major harbor improvements at Morehead City Harbor.

Existing data that has been collected over the years in connection with the navigation project and other studies in the area was used in this study. The study analysis included the following: construction and maintenance history; physical changes in Beaufort Inlet, sediment budget; prior impact assessments; and project impacts on adjacent shorelines. The study presented the analysis that was used to determine if there were project impacts to adjacent shorelines and summarized these findings.

The completed Section 111 study was performed for the Wilmington District by a consultant who is widely respected as a coastal engineer. Wilmington District staff members have reviewed the study. The study has also benefited from a peer review by nationally recognized coastal engineers with the U.S. Army Engineer Research and Development Center in Vicksburg, Mississippi, and also by an experienced coastal engineer with the Jacksonville District, U.S. Army Corps of

Engineers. At the request of the Director, Division of Water Resources, North Carolina Department of Environment and Natural Resources and the Executive Director of the North Carolina State Ports, the District Engineer has provided the Section 111 report for their review

CONCLUSION: The study found that the shoreline change rates for the Town of Pine Knoll Shores were basically the same for the period with the navigation project as for the period prior to the navigation project. The shoreline change rate for the period with the navigation project (1978 to 2001) was found to be -2.6 feet per year. The shoreline change rate for the period prior to the navigation project (1877 to 1933) was found to be -2.3 feet per year. The slight increase in the average erosion rate for the period with the navigation project (average of less than four inches per year) is within the error limits associated with the shoreline change data used in the analysis, and therefore cannot be viewed as being significant. Not only is there no direct evidence that the harbor project has had a negative impact on the Pine Knoll Shores shoreline, there is no evidence that the harbor project has had an impact on any of the other shorelines in the vicinity of the harbor project. Therefore, mitigation for shoreline damages under the continuing authority provided by Section 111 of Public Law 90-483, as amended, is not warranted.

Erosion of the western segments of Bogue Banks during the with-project period, as well as the Pine Knoll Shores segment was primarily associated with storm activity that reached a peak during the 1993 to 1999 period. Between 1993 and 1999, the Bogue Banks area was impacted by 12 tropical storm events, 7 of which were categorized as moderate to severe. The moderate to severe storms included Hurricane Emily in August 1993, Hurricane Gordon in November 1994, Tropical Storm Arthur in June 1996, Hurricane Bertha in July 1996, Hurricane Fran in September 1996, Hurricane Bonnie in August 1998, and Hurricane Floyd in September 1999.

As for the disposal of dredged material on the beaches, the U.S. Army Corps of Engineers policy concerning the placement of dredged materials on beaches is that the construction and maintenance dredging of Federal navigation projects should be accomplished in the least costly manner possible. When placement of dredged material (beach quality sand) on a beach is the least costly acceptable means of disposal, then such placement is considered integral to the project and cost shared accordingly. When placement of dredged material on a beach costs more than the least costly alternative, the Corps may participate in the additional placement costs under the authority of Section 145 of the Water Resources Development Act of 1976, as amended (Section 933 - Public Law 99-662). The additional costs of placement may be shared on a 65 percent Federal and 35 percent non-Federal basis if: (1) requested by the State; (2) the Secretary of the Army considers it in the public interest; (3) the added cost of disposal is justified by hurricane and storm damage reduction benefits; and (4) the shoreline on which the material is placed is open to public use.

An example of least cost beach disposal is the Federal maintenance of the inner harbor at Morehead City, which is performed by pipeline dredge with disposal on Brandt Island. This is a confined dredged material disposal site located immediately across the harbor from the State Port facility. Due to the limited 8 to 10 year capacity of this site, and the absence of other suitable upland disposal sites in the area, Brandt Island was identified as a temporary holding area for the inner harbor dredged material during the formulation of the 40-foot project in 1976. Maintenance material is stored on Brandt Island for a period of 8 to 10 years after which time the material is transferred to a beach disposal site. The designated beach disposal site begins at the Fort Macon State Park terminal groin and extends 7 miles to the west, ending at the Corps of Engineers baseline station 410+00. Transfer of material from Brandt Island to the beach was accomplished in 1986 (3,913,000 cubic yards) and again in 1994 (3,183,000 cubic yards) as the least costly acceptable means of disposal.

In addition to the material from Brandt Island, there was also new work construction material placed along the Fort Macon shoreline in 1978 (1,170,000 cubic yards) and again in 1994 (1,481,000 cubic yards). There was also 256,000 cubic yards of channel maintenance material placed along the designated beach disposal site in 1986. Therefore, a total volume of about 10,013,000 cubic yards of beach material has been returned to the beach by dredge disposal operations. Based on a compatibility analysis of the inner harbor shoal material placed on the beach, 69 percent of this material was littoral sand. Therefore, the net fill provided along the Atlantic Beach and Fort Macon shorelines by these beach disposal operations was about 6,909,000 cubic yards.

STATUS REPORT ON OTHER STUDIES OF BOGUE BANKS: There are other ongoing considerations to address shore protection in the area that will continue. Congress has authorized a cost shared feasibility study of Bogue Banks to investigate shore protection needs for the communities of Atlantic Beach, Pine Knoll Shores, Indian Beach, Salter Path and Emerald Isle Beach. Carteret County is the non-Federal cost-sharing sponsor. In addition, the State of North Carolina has requested a Section 933 (Public Law 99-662) Study for Morehead City Harbor (Bogue Banks). This study will investigate the beneficial use of dredged material from the Morehead City Harbor navigation project for the purposes of beach nourishment along Bogue Banks beaches. The status of these studies is shown below:

Bogue Banks Shore Protection Study - The cost shared feasibility phase was initiated in February 2001 and is scheduled for completion in March 2005 with the signing of the Record of Decision. If the study findings result in an economical and environmentally feasible alternative and the sponsor supports the recommendation, the study will be forwarded to Congress for approval. The Preconstruction, Engineering, and Design (PED) phase is scheduled to be initiated in 2005. The PED phase normally takes 24 to 36 months to complete for shore protection projects.

The construction phase normally takes about 24 months to complete based on Congressional approval and funding for the project

Section 933 Morehead City Harbor (Bogue Banks) Study - The feasibility study is currently unfunded however; Senator Edwards was successful in having the Senate version of the Fiscal Year 2002 Appropriations bill amended to include $300,000 for the study. These funds must survive the conference before they would be available for the study. Once funding has been received, the feasibility study will be initiated. It is anticipated that this study will take about 24 months to complete. If the study findings result in an economical and environmentally feasible alternative and the sponsor supports the recommendation, the study will be forwarded to the Assistant Secretary of the Army for Civil Works for approval. Based on the availability of funds in the Corps Operations and Maintenance (O&M) program and funding from the local sponsor, PED and construction can be accomplished. The PED phase normally takes 6 to 12 months for 933 projects. The construction phase normally takes 6 to 12 months to complete and would be conducted in conjunction with the navigation O&M action.

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1.0 INTRODUCTION

1.1. Study Authority and Scope. This study was conducted under the authority of Section 111 of Public Law 90-483 as amended by Section 915 (f) and 940 of Public Law 99-662. In August 1994, the Town of Pine Knoll Shores contacted the Wilmington District Corps of Engineers with concerns over an apparent increase in the rate of erosion along its ocean shoreline. The Town of Pine Knoll Shores, which is located as shown on Figure 1.1, is an ocean front community with a 4.5 mile-long ocean shoreline that begins 6 miles west of Beaufort Inlet. Beaufort Inlet serves as the entrance to Morehead City Harbor. Following this initial contact, several meetings were held with town officials to discuss various erosion response options available to the town. The town officials contented that their shoreline began to experience accelerated erosion immediately following the 1994 deepening of the Morehead City Harbor project from 40-feet mean low water (mlw) to 45-feet mlw. During the deepening of the project, some of the dredged material was deposited on the shoreline fronting the Town of Atlantic Beach. The disposal of this material on the beach, which abruptly terminated near the east town limits of Pine Knoll Shores, created a wide offset in the alignment of the beach between Atlantic Beach and Pine Knoll Shores (see Photo 1.1) and was perceived by the town officials and local residents as having contributed to the increased erosion. As a result, the Town requested that the Corps conduct a study to determine if the increase in the erosion rate was related to the operation and maintenance of the Morehead City Harbor project. The Wilmington District received funds in February 1997 to initiate the study.

1.2. Even though the request for the Section 111 study was initiated by the Town of Pine Knoll Shores, the evaluation of the potential impacts of the harbor project on the adjacent shorelines includes consideration of potential impacts east and west of the harbor entrance. The island to the east of the entrance is known as Shackleford Banks (see Figure 1.2). Shackleford Banks, which is approximately 8.7 miles long, is bordered on the east by Barden Inlet and is part of the Cape Lookout National Seashore. Bogue Banks is the island located west of the entrance and is approximately 24 miles long and is bordered on the west by Bogue Inlet. Bogue Banks is divided into several political subdivisions including the Fort Macon State Park on the extreme east end and the Towns of Atlantic Beach, Pine Knoll Shores, Indian Beach, and Emerald Isle.

1.3. Section 111 authority is limited to correcting damages to shorelines that can be directly attributable to Federal navigation projects. Accordingly, the focus of this study will be on the evaluation of changes in shoreline behavior on both Bogue Banks and Shackleford Banks that occurred following the implementation of major harbor improvements at Morehead City Harbor. The study also includes an evaluation of the physical changes that have taken place in Beaufort Inlet and the adjacent offshore areas resulting from the harbor project and the impact that these physical changes have had on wave transformations and potential longshore sediment transport rates on Bogue Banks and Shackleford Banks.

1.4. Tides and Tidal Datums. The mean tide range measured at the Triple S pier on Atlantic Beach (see Figure 1.1) by the National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) is 3.7 feet with a mean spring tide range of 4.3 feet. Mean low water (mlw) is 1.5 feet below the National Geodetic Vertical Datum (NGVD). NGVD is referred to as mean sea level (msl) in this report. The ocean tides are semidiurnal with almost equal high and low tides during successive tidal cycles.
Inside the inlet, the mean tide range is 3.0 feet at the State Port and at the Duke University Marine Laboratory (see Figure 1.1).

1.5. Corps of Engineers Baseline. Throughout this document, reference will be made to stationing along the Corps of Engineers baselines on both Bogue Banks and Shackleford Banks. In the case of the Bogue Banks baseline, stationing begins on the sound shoreline of Fort Macon Point and wraps around the point such that the stationing for the terminal groin located on the extreme east end of the island is at baseline station 25+64 (see Figure 1.1 and 1.2). Stationing along the baseline increases in an east to west direction. On Shackleford Banks, baseline station 0+00 is located adjacent to Barden Inlet with baseline stationing also increasing in an east to west direction. The relative locations of baseline stations on Shackleford Banks are shown on Figure 1.2.

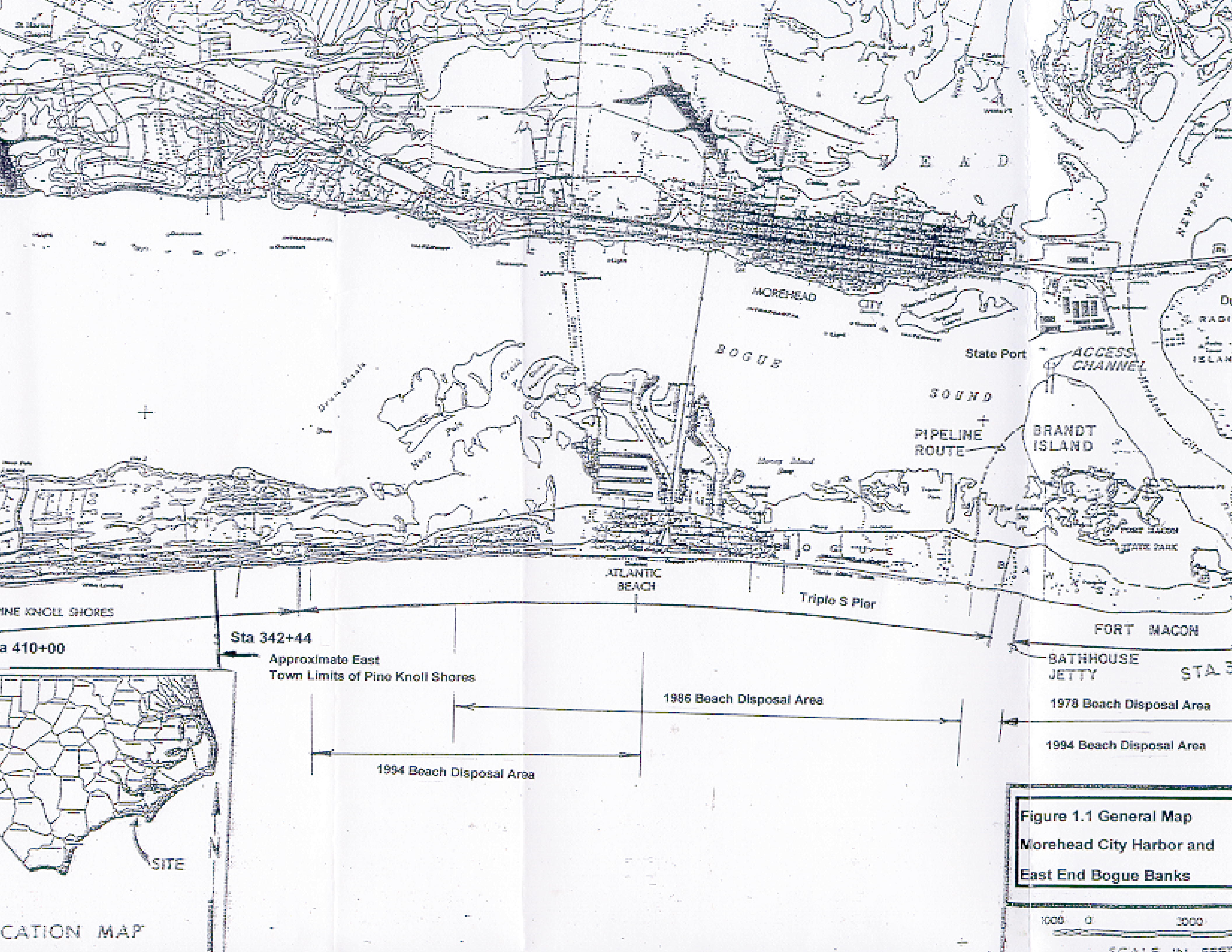


Figure 1.1 General Map Morehead City Harbor and East End Bogue Banks

Figure 1.2
Vicinity Map

2.0 PROJECT DESCRIPTION

2.1. Description of the Morehead City Harbor Project. The Morehead City Harbor project presently consists of a 47-foot deep (mlw) by 450-foot wide ocean entrance channel through the ocean bar of Beaufort Inlet, which connects with channels and an inner harbor which is generally 45 feet deep at mlw. The current project is generally referred to as the 45-foot project. A map of the Morehead City Harbor project is shown on Figure 2.1. Note that the entrance channel is composed of three reaches; namely; Range B, the Cutoff, and Range A (see Figure 2.1). The primary commodities passing through the Morehead City are phosphate products and imported rubber, which are handled by facilities provided by the North Carolina State Port Authority. Significant quantities of liquid fertilizer and woodchips also pass through the State Port. Privately operated liquid storage facilities are located at the State Port, Radio Island (see Figure 2.1) east of the State Port proper complex.

2.2. Historically, the Cutoff and Range A have been maintained by hopper dredge with the dredged material deposited in an offshore dredged material disposal site (ODMDS) located west of the seaward end of the bar channel. The location of the ODMDS is shown on Figure 2.2. During the 1996 maintenance cycle for the bar channel, the disposal location was modified to include an option for near shore placement west of the bar channel in an area centered on the 30-foot mlw depth contour. Subsequent maintenance operations conducted in 1997 to 1999 required that all ocean bar channel material be placed in a near shore disposal site centered on the 25-foot mlw contour west of the channel. The location of the 25-foot mlw site is shown on Figure 2.3. However, operational constraints associated with the operation of hopper dredges has not allowed all of the maintenance material to be placed in the near shore site. The constraints associated with a hopper dredge operation include the inability of the dredge to deposit the material in shallow depths during unfavorable weather and wave conditions and the restricted dredging window (i.e., the time period in which hopper dredges are allowed to operate) imposed on hopper dredge operations due to their propensity to cause harm and even kill sea turtles. The dredging window for hopper dredges extends from December through February.

2.3. Maintenance of Range B and the inner harbor has been performed by pipeline dredge with disposal on Brandt Island, a confined dredged material disposal site located immediately across the harbor from the State Port facility (see Figure 2.1). Due to the limited capacity of this site, and the absence of other suitable upland disposal site in the area, Brandt Island was identified as a temporary holding area for the inner harbor dredged material during the formulation of the 40-foot project in 1976. In this capacity, maintenance material is to be temporally stored on the Brandt Island for a period of 8 to 10 years after which the material is transferred to a beach disposal site located along the eastern end of Bogue Banks. The designated beach disposal site begins at the Fort Macon State Park terminal groin and extends 7 miles to the west, ending at Corps of Engineers baseline station 410+00 (see Figure 1.1). Transfer of material from Brandt Island to the beach was accomplished in 1986 and 1994.

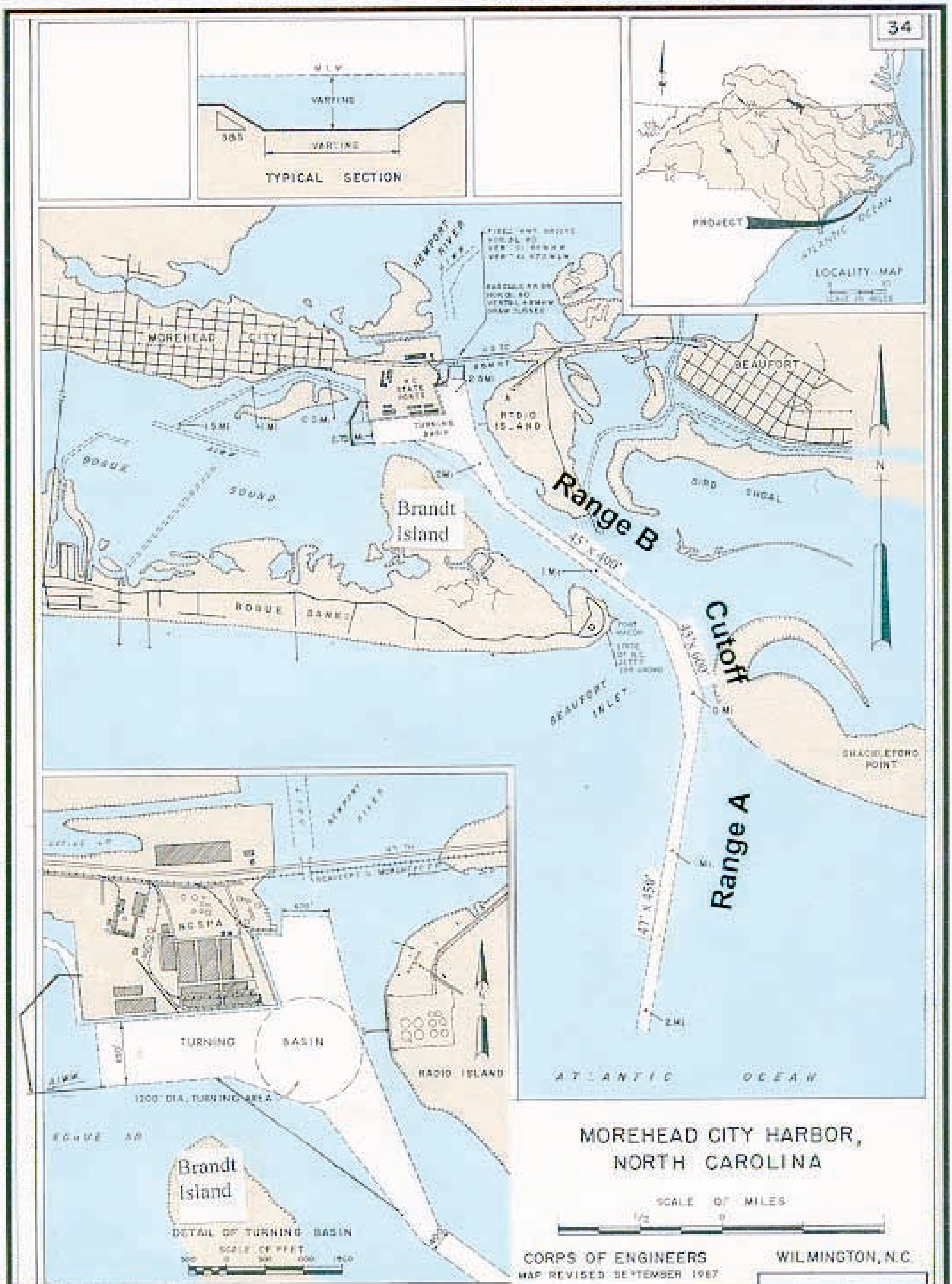


Figure 2.1 Morehead City Harbor Project Map

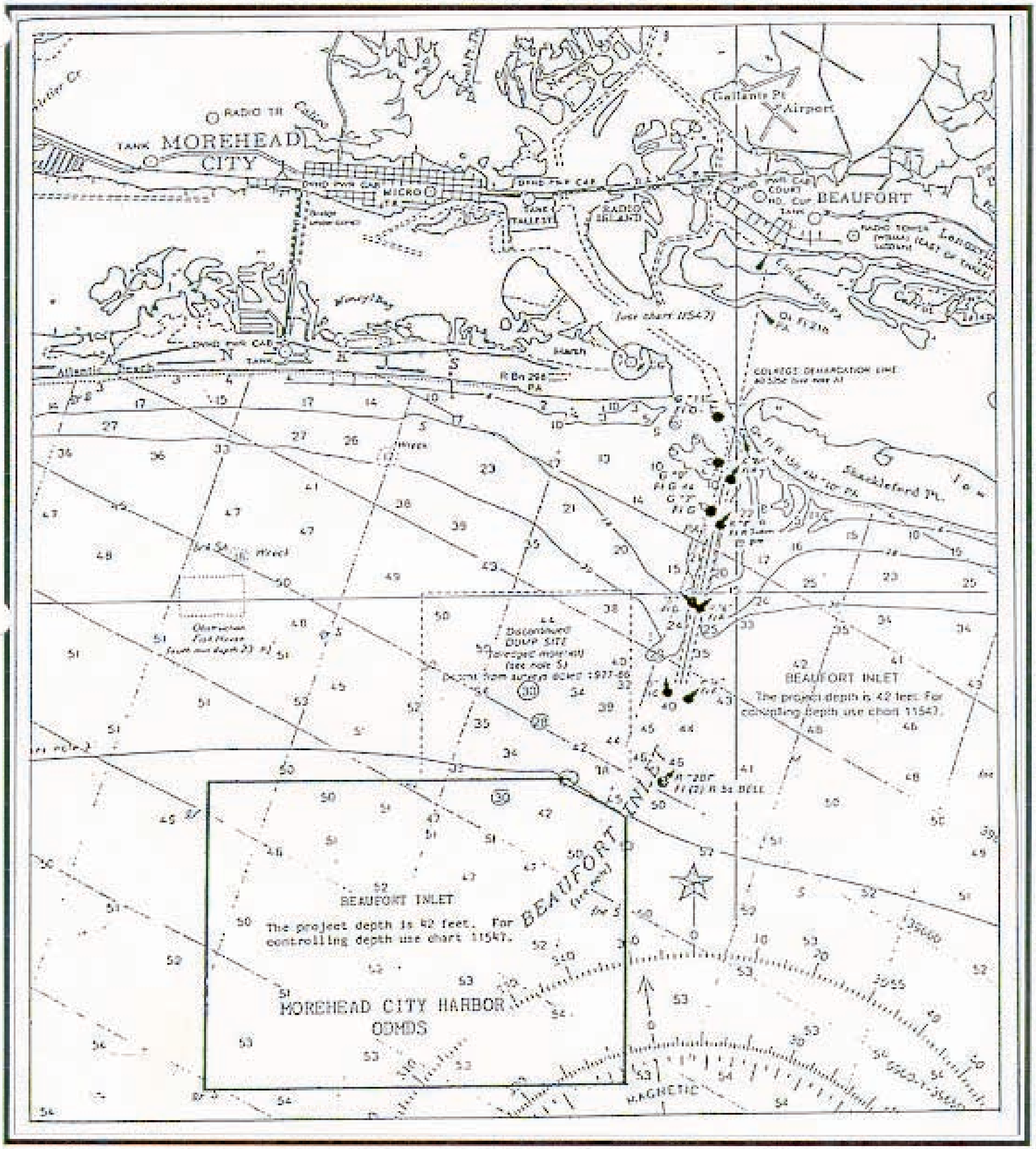


Figure 2.2 Morehead City Harbor Ocean Dredged Material Disposal Site (ODMDS)

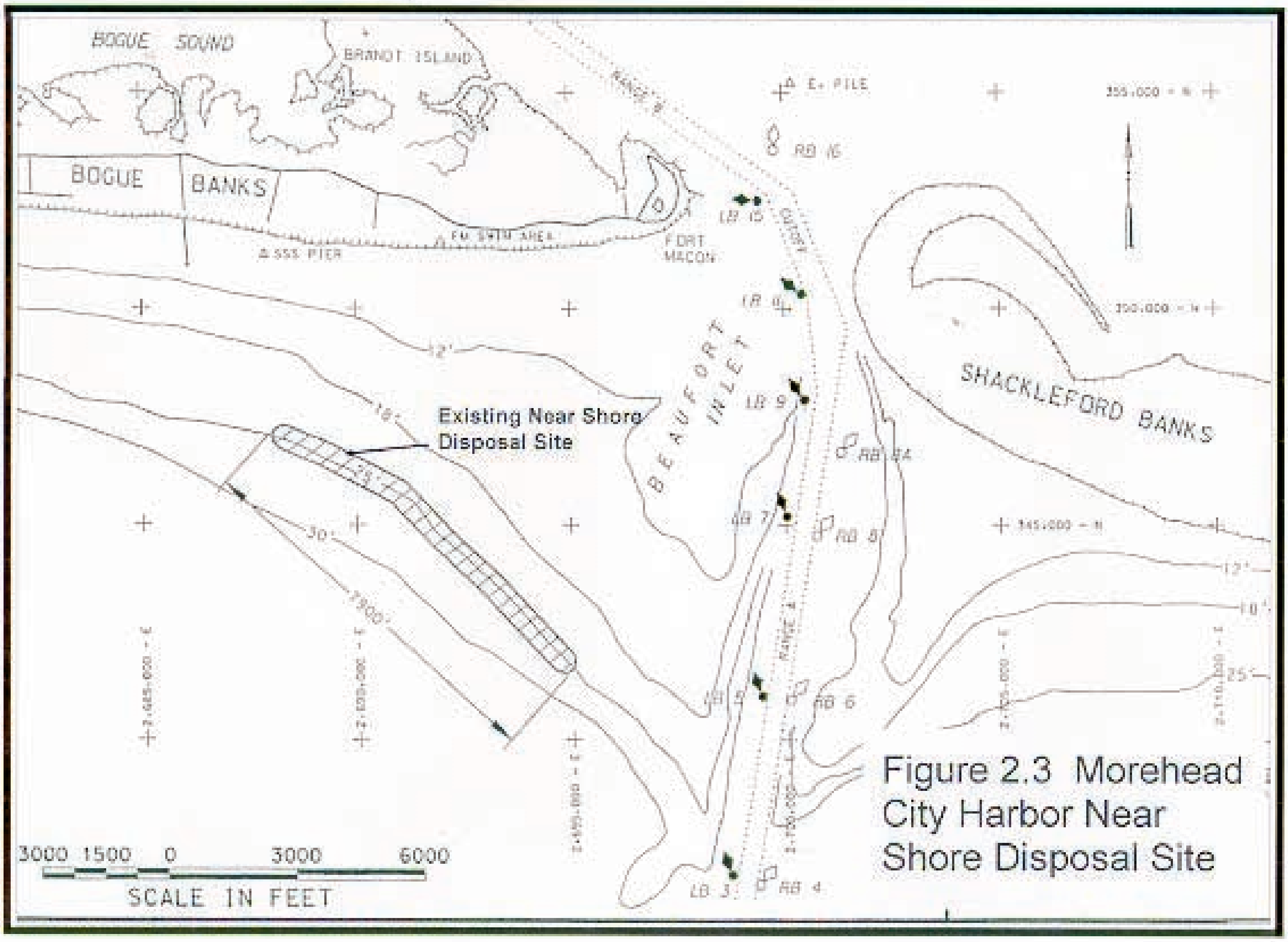


Figure 2.3 Morehead City Harbor Near Shore Disposal Site

3.0 PROJECT CONSTRUCTION AND MAINTENANCE HISTORY

3.1. Project Improvement History. Dredging of the ocean bar channel began in 1911 with the excavation of a channel 20 feet deep at mlw by 300 feet wide. These channel dimensions were maintained until 1935 by conducting maintenance dredging along the naturally deep channel, that is, no attempt was made to keep the channel in a fixed location. The dimensions of the bar channel were increased to 30 feet deep at mlw by 400 feet wide in 1936 and to 35 feet deep at mlw by 400 feet wide in 1961. The 30-foot and 35-foot deep bar channels were maintained along a fixed alignment. Also, the inner harbor channels and basin were dredged to the same depths as the bar channel. In 1978, the bar channel was deepened to 42-feet and widened to 450 feet while the interior channels and basin were deepened to 40-feet mlw. These particular project dimensions are referred to as the 40-foot project. The additional 2 feet of depth in the bar channel over the interior channels was provided to account for the vertical motion of ships associated with wave action. During construction of the 40-foot project, the alignment of the ocean bar channel was modified slightly from that maintained in connection with the 30- and 35-foot projects to take advantage of naturally deep water on the east side of the channel near Shackleford Point. In this regard, the near shore portion of the Beaufort Inlet ebb tide delta off Fort Macon has a tendency to migrate to the east. As a result, the Cutoff and the landward portion of Range A experience severe and rapid shoaling. The eastward movement of this portion of the ebb tide delta has pushed the throat or gorge of the inlet toward Shackleford Point. The slight eastward shift in the location of the bar channel in 1978 greatly reduced the amount of dredging required to construct the 42-foot mlw entrance channel and subsequently reduced annual maintenance dredging for a short period following the channel relocation. In 1994, the project was modified to its present dimensions, which includes a 47-foot deep mlw by 450-foot wide ocean bar channel, a 600-foot wide by 47-foot deep Cutoff, three channel wideners, and 45-foot deep interior channels and basin.

3.2. Dredging History (New Work). The volume of material removed from Beaufort Inlet and the inner channels and basin during the construction of the various harbor improvements since 1911 are provided in Table 3.1. All of the material removed from the bar channel by hopper dredge was deposited in the ODMDS. Material removed during the deepening of the inner harbor in 1936 and 1961 was deposited on Brandt Island whereas the inner harbor material removed during the 1978 and 1994 deepening projects was placed on the east end of Bogue Banks. The inner harbor material removed during the 1978 deepening was placed on the shoreline fronting the Fort Macon State Park. The 1994 material was placed on the west half of the Atlantic Beach shoreline and the Fort Macon State Park shoreline. Additional discussion of the beach disposal operations is provided in paragraph 3.5 with an evaluation of the performance of the fills given in Section 7 of this report.

Table 3.1
Historical New Work Dredging Volumes

Year	Bar Channel Dimensions (ft)	Hopper Dredge Volume (a) (cy)	Inner Harbor Channel & Basin depths (ft mlw)	Pipeline Dredge Volume (cy)	Inner Harbor Disposal Area
1911	20 x 300	37,000	20	0	*****
1936	30 x 400	3,460,100	30	2,367,900	Brandt Island
1961	35 x 400	1,869,200	35	1,336,600	Brandt Island
1978	42 x 450	2,972,200	40	1,179,600	Bogue Banks
1994	47 x 450	2,112,600	45	1,725,000	Bogue Banks
1936-94		**10,414,100**		**6,609,100**	

(a) Hopper Dredge material deposited in the ODMDS

3.3. Maintenance Dredging History. Maintenance dredging of the ocean bar channel and the inner channels for the various project dimensions are summarized in Table 3.2. The maintenance dredging for the inner harbor includes Range B and the basins opposite the N.C. State Port Facility. The entrance channel includes the Cutoff and Range A. The amount of dredging performed each fiscal year since 1911, including maintenance and new work dredging, is provided in Table B-1 in Appendix B. All of the material removed from the entrance channel prior to 1996 was deposited in the ODMDS. Beginning in 1996, attempts have been made to deposit the bar channel maintenance material in near shore disposal sites located west of the inlet. The purpose of placing material in the near shore site was to keep it within the active littoral zone of the area and to allow the deposited material to migrate back onto and nourish the ebb tide delta of Beaufort Inlet. As discussed later, the ebb tide delta of Beaufort Inlet has experienced significant erosion or deflation since 1952. Monitoring of the 30-foot mlw disposal site indicated very little movement of the deposited material. Accordingly, the near shore placement site was moved closer to shore in 1997 and centered on the 25-foot mlw depth contour as shown on Figure 2.3. Since 1997, approximately 1 million cubic yards of ocean bar channel maintenance material, or slightly less than one-half of the total volume removed from the channel since 1997, has been placed in the near shore site. Monitoring of the 25-foot mlw disposal site has indicated very little movement of the deposited material thus far. As discussed above, material removed to maintain the inner harbor is presently stored on Brandt Island for a period of 8 to 10 years after which time it is removed and placed on the east end of Bogue Banks.

3.4. A graph of the average annual maintenance dredging performed in the ocean bar channel and the inner harbor as a function of project depth is shown on Figure 3.1. In general, maintenance dredging requirements in both the entrance channel and inner harbor have increased with each incremental increase in project depth. The one exception was for the ocean bar channel in which the average annual amount of maintenance dredging decreased slightly when the channel was deepened from 35 feet mlw to 42 feet mlw. The primary factor contributing to this decrease in annual maintenance was the slight realignment of the entrance channel to the east toward Shackleford Point during construction of the 42-foot mlw channel, which was made to take advantage of naturally deepwater in this location. As a result of the channel alignment shift, no maintenance dredging was required in 1979 and only 294,600 cubic yards was removed in 1980.

Table 3.2
Historical Average Annual Maintenance Dredging Volumes

Bar Channel Dimensions (ft)	Time Period (years)	Hopper Dredge Volume Ocean Bar (cy/yr)	Inner Harbor Project Depth (ft mlw)	Pipeline Dredge Volume Inner Harbor (cy/yr)
20 x 300	1911-1935	99,800	20	0
30 x 400	1937-1960	534,500	30	122,400
35 x 400	1962-1977	650,200	35	125,100
42 x 450	1978-1994	591,600	40	227,100
47 x 450	1996-2000	950,900	45	221,600

3.5. Beach Disposal of Dredged Material. Material removed from the Morehead City Harbor project in conjunction with maintenance or initial construction of harbor improvements has been deposited on the shoreline of Bogue Banks on three separate occasions. In 1978, during the construction of the 40-foot mlw project, 1,179,600 cubic yards of material removed for the deepening of the inner harbor and Range B was deposited along the Fort Macon State Park shoreline. This disposal area is shown on Figure 1.1. In 1986, the Brandt Island disposal area was dredged for the first time with 3,912,900 cubic yards being deposited on the Bogue Banks shoreline between Corps of Engineers baseline stations 100+00 and 290+00 (see Figure 1.1). In addition to the Brandt Island material, 255,700 cubic yards of channel and basin maintenance material was transferred directly to the beach disposal site resulting in a total deposition along this section of Bogue Banks of 4,168,600 cubic yards. During the 1994 construction of the 45-foot mlw project, a total of 4,664,400 cubic yards of dredged material was placed on Bogue Banks with 3,183,400 cubic yards deposited between baseline stations 210+00 and 318+00 (see figure 1.1) and the remaining 1,481,000 placed on the shoreline fronting Fort Macon State Park. Of the total 4,664,400 placed on the beach, 465,700 cubic yards was maintenance material from the inner harbor, 1,725,000 cubic yards was for new work construction, and 2,473,700 cubic yards was from the Brandt Island disposal area. The western limit of the 1994 beach disposal operation was near the east town limit of Pine Knoll Shores as shown on Photo 1.1.

3.6. Shoal Material Characteristics. There are four sources of material that shoal the inner harbor and entrance channel, namely, the adjacent beaches, the ebb tide delta of Beaufort Inlet, riverine sediments from the Newport River and North River, and estuarine sediments transported from the adjacent sounds and marshes. The shoal material derived from the adjacent beaches and the ebb tide delta of Beaufort Inlet are littoral materials consisting of quartz sand and shell fragments while the river and esturaine material is generally fine grained sand, silt, and clay. Since all of the shoal material is not littoral material, a comparison was made between the size characteristics of the material that shoals the inner harbor and the entrance channel with the size characteristics of the native beach materials to determine the percent of shoal material in each of the project areas that is beach material. The comparative analysis used the procedure described in the Shore Protection Manual (U.S. Army Corps of Engineers, 1984) to determine the compatibility of beach fill borrow material to the native beach material. The procedure consist of determining the composite characteristics of the native beach material and comparing those characteristics with the composite size characteristics of the borrow material, which in this case is the material removed from the inner harbor and the entrance channel. The analysis produces a number known as the Overfill Ratio (R_a) which is a measure of the number of cubic yards from the borrow source necessary to produce one cubic yard of compatible beach material. For example, if the analysis indicates an Overfill Ratio of 1.2, the percentage of material that is compatible with the native beach sand would be (1/1.2) or 83.3%. The compatibility analysis only compares the size distribution of the coarse material. If the borrow source contains some percentage of silt and clay, the portion of the borrow material suited for the beach would be further reduced by this percentage. In the example above, if the borrow material contained 10% silt and 90% sand, the amount of material in the borrow area compatible with the native beach material would only be 75% *(= .9 x 83.3%)*.

3.7. Native Beach Size Characteristics. Surficial samples of the native beach materials were collected from Atlantic Beach profile stations 70+00, 140+00, 219+00, and 290+00 in two-foot depth increments from elevation +8 feet mlw (+6 feet msl) seaward to a depth of –30 feet mlw. The mean and standard deviation of all of the samples are given in Table 3.3 along with the average size characteristics by sample depth. Note that the mean and standard deviations are expressed in phi units (Φ) where phi is related to the particle size in millimeters (mm) by the following:

$$\text{Phi units } (\Phi) = -\log_2 (\text{diameter (d) in mm})$$

The mean particle size for all the samples collected from the native beach is 2.53Φ or 0.17 mm. The composite standard deviation (σ_Φ) for all of the samples is 0.76Φ.

3.8. Characteristics of the Inner Harbor and Range B Shoal Material. The size characteristics of the shoal material in the inner harbor and Range B of the Morehead City Harbor project were determined from samples collected from numerous core borings. Only samples collected from the top of the core borings above previous dredging depths were used in this analysis as these samples represented shoal material. The location of the various core borings are shown on Figures 3.2 and 3.3. Note that the samples collected from boreholes labeled MH-90-15 to MH-90-17 on Figure 3.2 were excluded from the analysis as these cores were located in an area that had not been previously dredged. The size characteristics of each sample and the composite characteristics of all the samples are given in Table 3.4. The average mean particle size of the shoal material in the inner harbor and Range B is 1.89Φ (0.27mm), which is coarser than the mean particle size of the native beach material. However, the shoal

Table 3.3 Characteristics of Native Beach Material on Atlantic Beach

	Station 70+00			**Station 140+00**			**Station 219+00**			**Station 290+00**			**Average by Depth**		
Sample Depth (ft mlw)	Mean (phi)	Standard Deviation (phi)	Variance (phi)^2	Mean (phi)	Standard Deviation (phi)	Variance (phi)^2	Mean (phi)	Standard Deviation (phi)	Variance (phi)^2	Mean (phi)	Standard Deviation (phi)	Variance (phi)^2	**Mean (phi)**	**Standard Deviation (phi)**	**Variance (phi)^2**
8	2.53	0.30	0.09	2.28	0.45	0.20	2.45	0.30	0.09	2.18	0.38	0.14	**2.36**	**0.36**	**0.13**
6	2.37	0.38	0.14	2.57	0.52	0.27	2.33	0.40	0.16	2.03	0.46	0.21	**2.33**	**0.44**	**0.20**
4	2.58	0.27	0.07	2.38	0.35	0.12	2.50	0.31	0.10	1.94	0.70	0.49	**2.35**	**0.44**	**0.20**
2	2.25	0.44	0.19	2.18	0.40	0.16	2.13	0.36	0.13	1.97	0.41	0.17	**2.13**	**0.40**	**0.16**
0	1.66	0.87	0.76	1.83	0.75	0.56	1.72	0.52	0.27	0.34	1.37	1.88	**1.74**	**0.73**	**0.53**
-2	1.80	0.86	0.74	1.91	0.81	0.66	1.61	0.80	0.64	1.76	0.82	0.67	**1.77**	**0.82**	**0.68**
-4	2.59	0.39	0.15	2.19	0.59	0.35	2.71	0.46	0.21	2.48	0.51	0.26	**2.49**	**0.49**	**0.24**
-6	2.38	0.47	0.22	2.15	0.57	0.32	2.57	0.55	0.30	2.85	0.43	0.18	**2.49**	**0.51**	**0.26**
-8	2.57	0.38	0.14	2.52	0.40	0.16	2.37	0.54	0.29	2.56	0.56	0.31	**2.51**	**0.48**	**0.23**
-10	1.56	0.78	0.61	2.97	0.34	0.12	2.92	0.35	0.12	3.08	0.37	0.14	**2.63**	**0.50**	**0.25**
-12	1.31	0.60	0.36	3.10	0.35	0.12	3.02	0.42	0.18	3.01	0.48	0.23	**2.61**	**0.47**	**0.22**
-14	2.52	0.45	0.20	3.10	0.35	0.12	3.07	0.36	0.13	3.02	0.42	0.18	**2.93**	**0.40**	**0.16**
-16	2.36	0.52	0.27	3.07	0.39	0.15	3.11	0.37	0.14	3.08	0.42	0.18	**2.91**	**0.43**	**0.18**
-18	2.49	0.49	0.24	3.08	0.38	0.14	3.09	0.40	0.16	3.05	0.44	0.19	**2.93**	**0.43**	**0.18**
-20	2.45	0.50	0.25	3.05	0.41	0.17	3.12	0.38	0.14	3.06	0.43	0.18	**2.92**	**0.43**	**0.19**
-22	2.47	0.52	0.27	3.00	0.42	0.18	3.06	0.43	0.18	3.02	0.46	0.21	**2.89**	**0.46**	**0.21**
-24	2.86	0.34	0.12	3.01	0.41	0.17	3.00	0.49	0.24	2.79	0.68	0.46	**2.92**	**0.50**	**0.25**
-26	2.67	0.43	0.18	3.04	0.39	0.15	2.77	0.75	0.56	2.85	0.72	0.52	**2.83**	**0.60**	**0.35**
-28	2.59	0.52	0.27	2.33	1.05	1.10	2.25	1.21	1.46	2.59	0.87	0.76	**2.44**	**0.95**	**0.90**
-30	2.18	0.52	0.27	2.49	0.54	0.29	2.73	0.78	0.61	2.58	0.90	0.81	**2.50**	**0.70**	**0.50**
										Average all samples			**2.53**	**0.55**	**0.30**
										Average to -20 ft mlw			**2.47**	**0.50**	**0.25**
										Average to -12 ft mlw			**2.31**	**0.53**	**0.28**
										Composite Std Dev & Var all samples =				**0.76**	**0.57**
										Composite Std Dev & Var to -20 ft mlw =				**0.73**	**0.53**
										Composite Std Dev & Var to -12 ft mlw =				**0.74**	**0.55**

Table 3.4 Characteristics of Inner Harbor and Range B Shoal Material
(Note: Samples taken from the top of the cores)

Core Number	Mean (phi)	Standard Deviation (phi)	Variance (phi)^2
	Inner Harbor Samples		
1	2.73	0.33	0.11
2	2.80	2.18	4.75
3	2.71	0.24	0.06
4	1.13	1.51	2.28
5	1.77	0.80	0.64
6	1.62	2.55	6.50
7	2.90	0.72	0.52
8	2.67	2.60	6.76
9	2.71	0.24	0.06
10	2.15	0.59	0.35
11	0.43	1.57	2.46
12	2.20	0.36	0.13
MH-90-18	2.40	1.57	2.46
MH-92-1	2.96	0.41	0.17
MH-92-2	1.44	1.32	1.74
MH-92-3	2.32	2.22	4.93
MH-92-4	1.62	1.30	1.69
MH-92-5	2.13	1.45	2.10
MH-92-6	no sample	no sample	no sample
MH-92-7	2.02	0.42	0.18
	Range B Samples		
13	1.21	1.35	1.82
15	2.83	0.36	0.13
16	1.44	0.97	0.94
17	0.90	1.58	2.50
18	2.50	0.25	0.06
22	1.66	0.66	0.44
MH-92-8	1.51	1.66	2.76
MH-92-10	1.25	1.00	1.00
MH-92-11	0.68	1.55	2.40
MH-92-12	1.07	1.28	1.64
Averages	**1.89**	**1.33**	**1.77**
Composite Std Dev & Var =		**2.23**	**4.97**
Over Fill Ratio =	**1.3**		
Percent Silt & Clay =	**10**		
Percent of Inner Harbor and Range B			
shoal material that is littoral material =			**69 percent**

material has a much larger size distribution as indicated by the composite standard deviation of 2.23Φ compared to the standard deviation of the native beach material which is 0.76Φ. The Overfill Ratio for the inner harbor and Range B shoal material compared to the native beach characteristics is 1.3. The samples collected from the top of the cores contained an average of 10 percent silt and clay. Based on these size characteristics of the inner harbor and Range B shoal material, approximately 69 percent *(=(1/1.3) x 0 .90)* of the shoal material is littoral material. The remaining 31 percent is probably derived from the Newport and North Rivers as well as from sediments redistributed from the adjacent sounds and marshes.

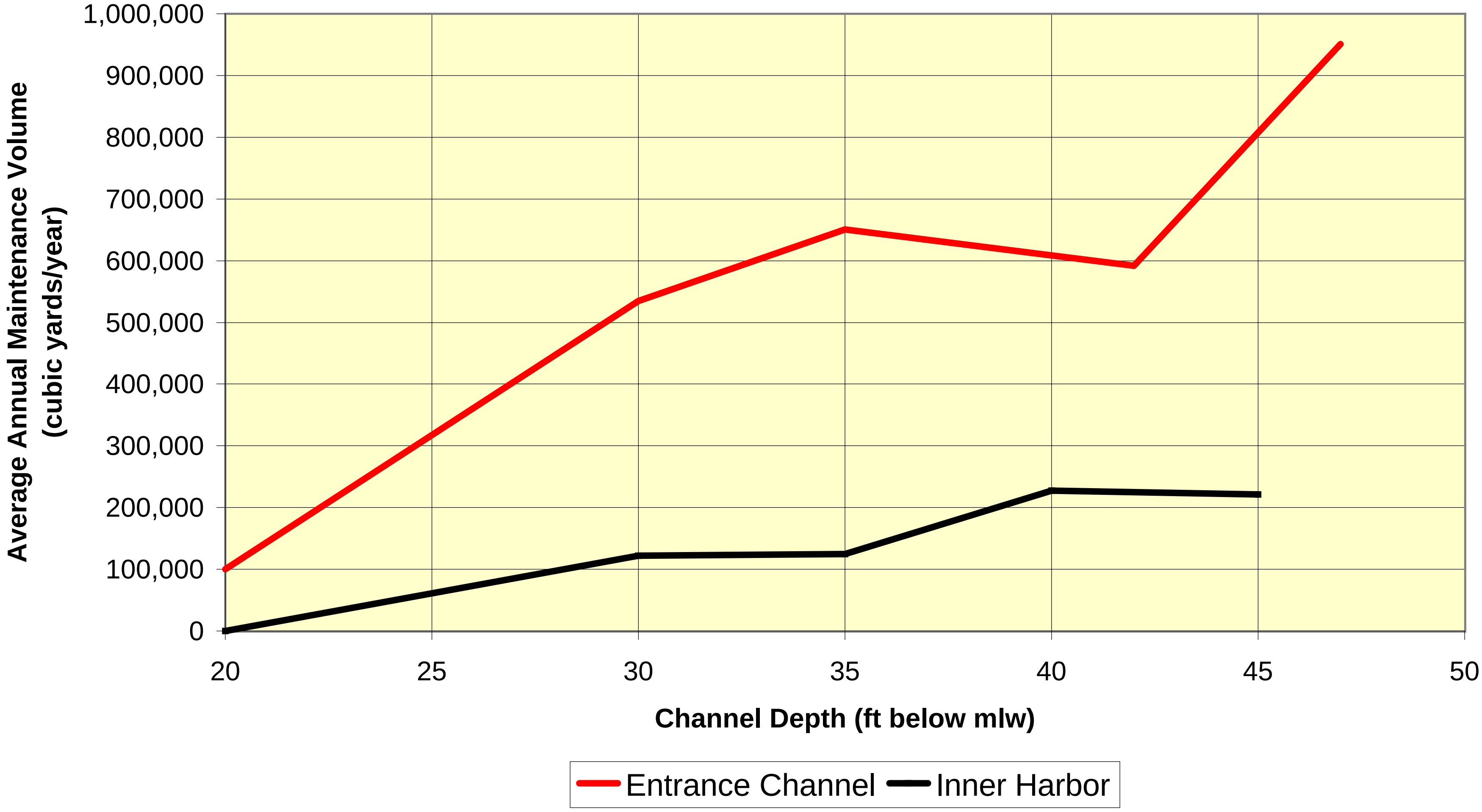
3.9. Characteristics of the Entrance Channel Shoal Material. The characteristics of the entrance channel shoal material were also obtained from the top samples taken from entrance channel borings shown on Figure 3.3. Again, only the samples collected above the previous dredging depths were used in the analysis. The size characteristics of each sample and the composite characteristics of all the samples taken from the entrance channel are given in Table 3.5. The composite mean particle size of the entrance channel shoal material is 1.95Φ (0.26mm) or essentially the same as the mean particle size of the inner harbor shoal material and again coarser than the composite mean of the native beach material. The grain size distribution of the entrance channel shoal material is also more widely distributed than the native beach material with a composite standard deviation of 1.27Φ compared to the composite standard deviation of the native material, which is 0.76Φ. The Overfill Ratio for the entrance channel material is 1.1. The amount of silt and clay in the entrance channel samples averaged about 5 percent. Thus, the material shoaling the entrance channel is 86 percent *(=(1/1.1) x 0.95)* littoral material. Again, the balance of 14 percent of the shoal material is probably derived from the Newport and North Rivers as well as from estuarine sediments that are resuspended and transported seaward during the ebb phase of the tidal cycle.

3.10. Entrance Channel Shoaling Characteristics. Previous analyses of the shoaling characteristics of the Morehead City Harbor entrance channel made in the 1976 General Design Memorandum (1976 GDM) for the 40-foot mlw project (U.S. Army Corps of Engineers, 1976) and 1990 Feasibility Study for the 45-foot mlw project (U.S. Army Corps of Engineers, 1990) found that between 65 and 70 percent of the shoaling occurs on the west side of the channel. Also, the 1976 GDM indicated that between 70 and 80 percent of the shoaling in the entrance channel occurs in a 6,000-foot channel segment from the middle of the Cutoff seaward. As mentioned previously, this shoaling pattern is associated with the eastward encroachment of the inner portion of the ebb tide delta located immediately off Fort Macon. An analysis of the distribution of shoaling along the present 47-foot mlw entrance channel is shown on Figure 3.4 along with the shoal distribution for the 35-foot mlw channel presented in the 1976 GDM. In the present channel (47-foot mlw), approximately 50 percent of the shoaling occurs in the first mile of the channel and over 70 percent occurs in the first 2 miles. The major differences in the shoal distribution pattern between the 35-foot mlw channel and the 47-foot mlw channel is that the 47-foot mlw channel is almost 5,000 feet longer than the 35-foot mlw channel. This additional channel length was required to extend the deeper entrance channel to the 47-foot depth contour in the ocean.

Table 3.5 Characteristics of Entrance Channel Shoal Material - Cutoff and Range A (Note: Samples Collected from the top of Cores)

Core Number	Mean (phi)	Standard Deviation (phi)	Variance (phi)^2
23	-0.28	0.66	0.44
24	0.2	1.13	1.28
25	0.53	1.3	1.69
27	1.7	0.78	0.61
28	2.08	1.39	1.93
32	2.57	0.17	0.03
33a	2.66	0.19	0.04
33b	2.71	0.24	0.06
33c	3.01	0.46	0.21
Ave 33	**2.79**	**0.32**	**0.10**
34	3.19	0.45	0.20
35a	2.94	0.47	0.22
35b	2.94	0.39	0.15
Ave 35	**2.94**	**0.43**	**0.19**
36a	2.77	0.3	0.09
36b	2.81	0.26	0.07
Ave 36	**2.79**	**0.28**	**0.08**
38	2.77	0.3	0.09
39	2.17	0.78	0.61
	1.95	**0.78**	**0.60**
Composite Std Dev & Var =		**1.27**	**1.61**
Over Fill Ratio =	**1.1**		
Percent Silt & Clay =	**5**		
Percent of Entrance Channel shoal material that is littoral material =		**86 percent**	

Figure 3.1 Entrance Channel and Inner Harbor Maintenance Dredging versus Channel Depth



Distribution of shoaling entrance
Dredging vs depth

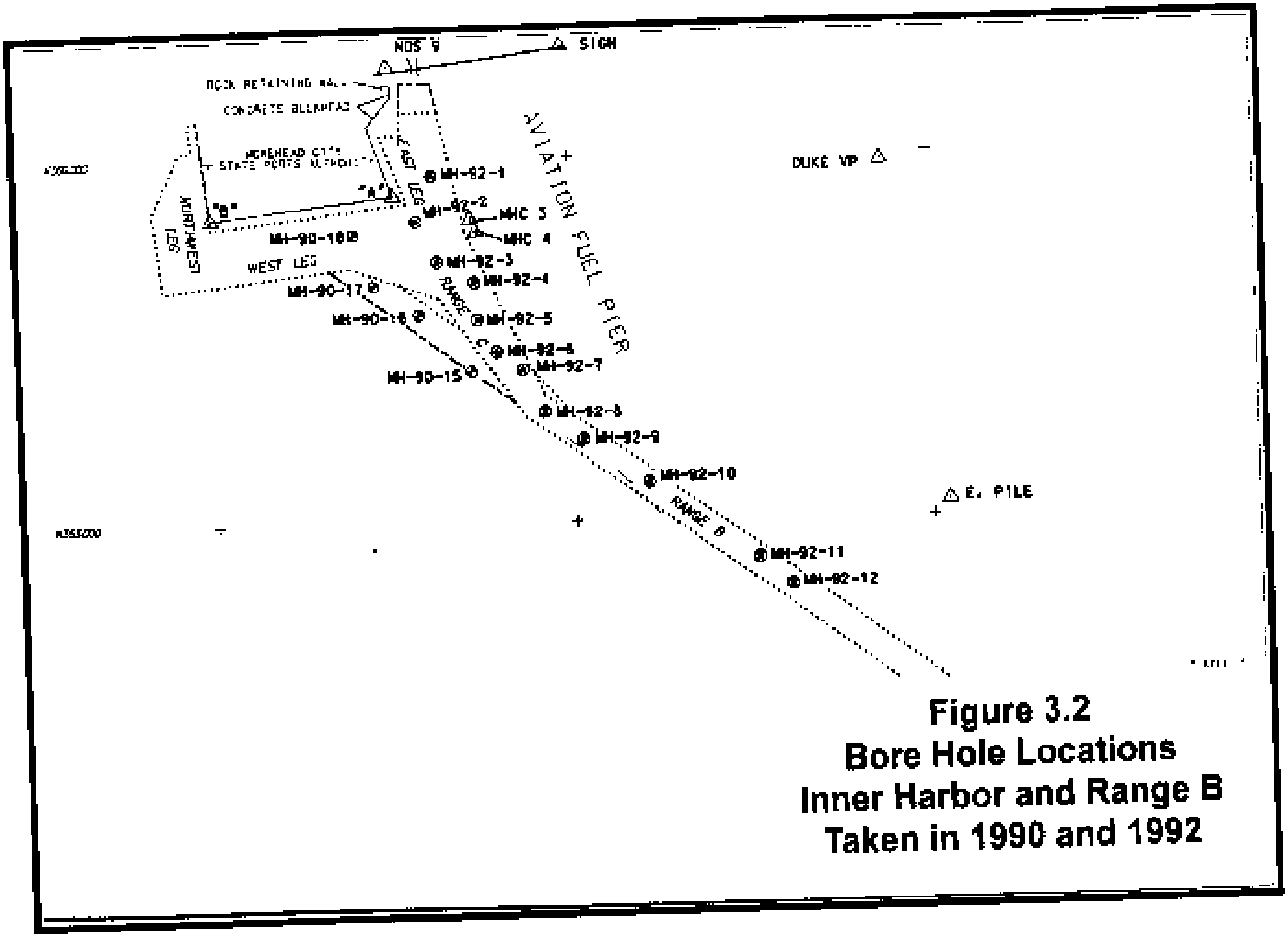
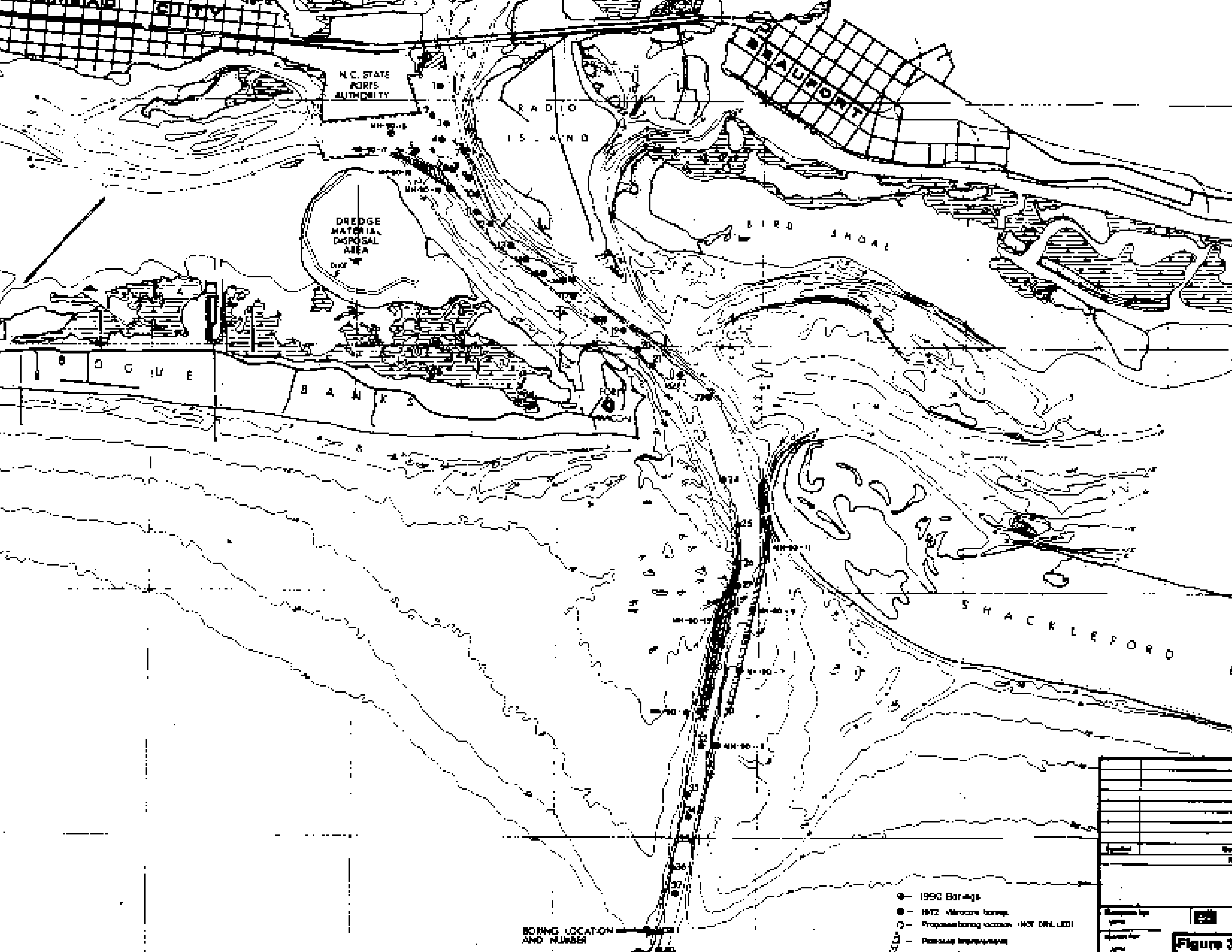


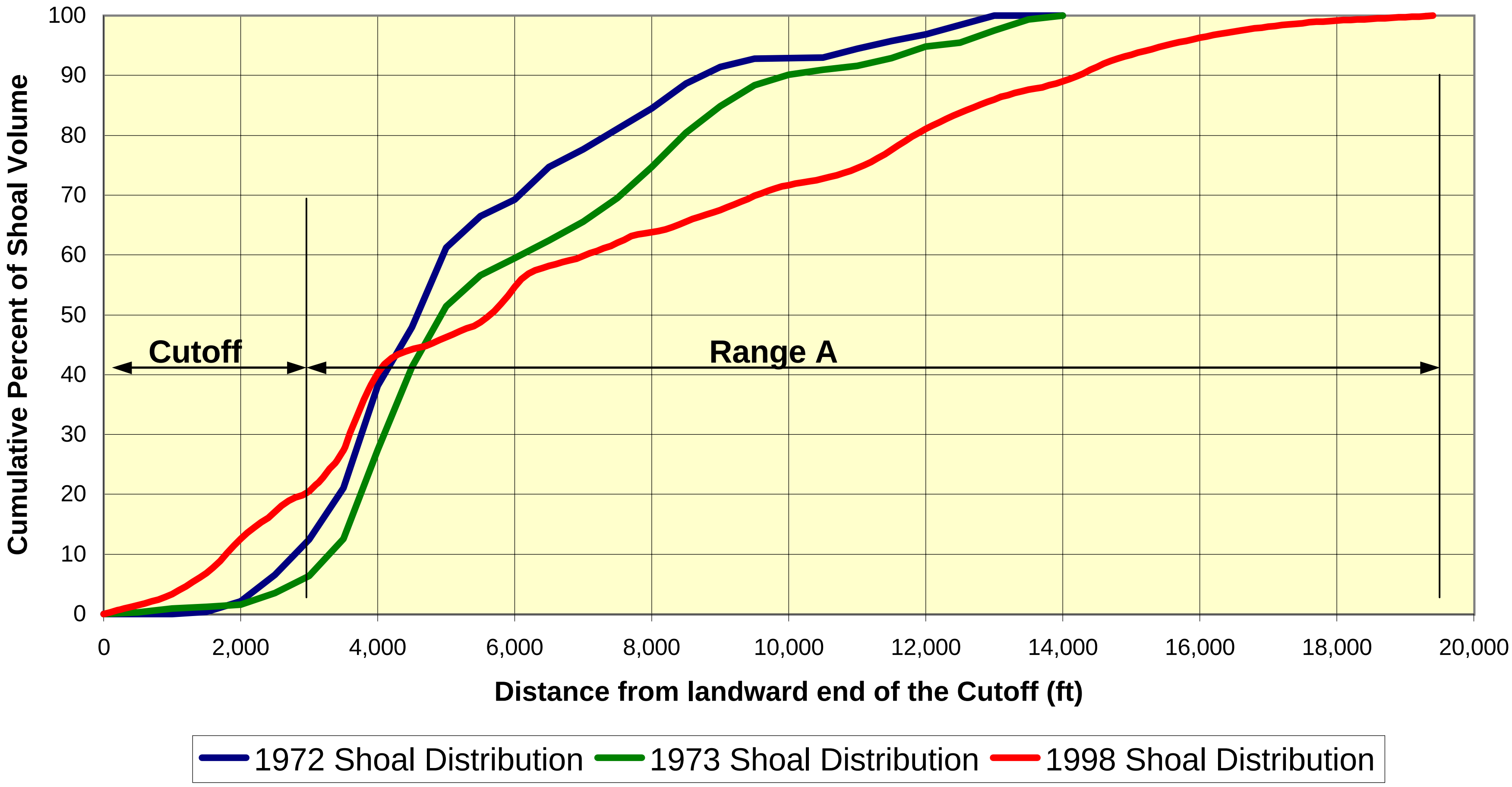
Figure 3.2
Bore Hole Locations
Inner Harbor and Range B
Taken in 1990 and 1992



N.C. STATE PORTS AUTHORITY
RADIO ISLAND
BEAUFORT
DREDGE MATERIAL DISPOSAL AREA
BIRD SHOAL
BOGUE BANKS
SHACKLEFORD
BORING LOCATION AND NUMBER
1990 Borings
Proposed boring location (NOT DRILLED)

Figure 3

Figure 3.4 Distribution of Maintenance Dredging
Morehead City Harbor Entrance Channel
Cutoff and Range A
35-foot mlw Channel (72 &73) and 47-foot mlw Channel (98)



Distribution of shoaling entrance
98, 72 73 plot

4.0 PHYSICAL CHANGES IN BEAUFORT INLET

4.1. Changes in the Beaufort Inlet Ebb Tide Delta. In the 1976 GDM, detailed hydrographic surveys of the Beaufort Inlet ebb tide delta made by the National Ocean Service (National Oceanic and Atmospheric Administration) in 1862, 1936, 1952, 1960, and 1974 were used to compute the change in volume of material on the bar. Comparison of the surveys were made by superimposing a grid with east-west spacings of 500 feet and north-south spacings of 250 feet and depths determined at each grid point. The east-west limits of this grid extended about 7,500 feet on either side of the west longitude 76^{o} 40’ while the north-south limits included the shoreline, or a projection of the shoreline across the inlet, and points 8,000 to 12,000 feet offshore. This grid area is shown on Figure 4.1. The grid on each survey was adjusted to the same horizontal datum and all depths measured relative to local mean low water. In 1988, the Corps of Engineers surveyed the ocean bar by running east to west cross-sections across the bar. These cross-sections were compared to similar cross-sections from the 1974 hydrographic survey by NOS to compute changes in the ebb tide delta between 1974 and 1988. The volumetric change in the ebb tide delta computed for each time interval between surveys is summarized in Table 4.1. Also given in Table 4.1 is the average annual rate of ebb tide delta volume change and a number referred to as the storm intensity factor (SFI). A discussion of the storm intensity factor is provided later in paragraph 4.10.

4.2. Changes in the volume of the ebb tide delta during the various time intervals given in Table 4.1 include new work dredging that occurred during the survey period. For example, the change in the ebb tide delta volume between 1862 and 1936 includes the 3,460,100 cubic yards of material removed from the delta in 1936 to construct the 30-foot mlw ocean entrance channel. Similarly, the 1960 to 1974 volume change includes the 1,869,200 cubic yards removed in 1961 to deepen the channel to 35 feet mlw and the 1974 to 1988 volume change includes the 2,972,200 cubic yards of new work dredging in 1978 to deepen the channel to 42 feet mlw. These new work volumes removed during the survey period were added to the measured volume changes from the survey comparisons to determine the volume changes on the delta outside the bar channel. The estimated volume change outside the ocean bar channel, which are given in Table 4.1, represent natural ebb tide delta volume changes that are caused by the influence of tidal currents, tides, and wave action.

4.3. Estimated Changes in the Ebb Tide Delta Since 1988. Hydrographic surveys of the ebb tide delta of Beaufort Inlet have not been made since 1988. Therefore, the changes in the ebb tide delta since 1988 were estimated based on the average rate of ebb tide delta change measured between 1960 and 1988. Between 1960 and 1988, the average rate of ebb tide delta deflation outside the bar channel area was 162,500 cubic yards/year (*=(-263,200 cy/yr for 1960 to 1974 – 61,700 cy/yr for 1974 to 1988)/2).* Multiplying this annual rate by 12 years results in the estimated total volume change on the bar outside of the channel area of – 1,950,000 cubic yards. New work dredging in 1994 to deepen the bar channel to –47 feet mlw totaled 2,112,600 cubic yards. Adding this volume removed to the estimated volume change outside the channel results in the estimated total ebb tide delta volume change for the 1988 to 2000 period of –4,062,600 cubic yards (see Table 4.1).

Table 4.1
Beaufort Inlet Ebb Tide Delta Volume Changes

Ebb Tide Delta Survey Dates	Ebb Tide Delta Volume Change From Map Comparisons (cubic yards)	New Work Dredging performed between the survey dates (cy)	Ebb Tide Delta Volume Change outside the channel area (cy)	Annual rate of delta volume change outside the channel area (cy/yr)	Average Annual Storm Intensity Factor (SFI)
1862 – 1936	-3,000,000	3,460,100	+460,100	+6,200	175.7
1936 - 1952	+2,929,000	0	+2,929,000	+183,062	88.5
1952- 1960	-9,129,000	0	-9,129,000	-1,141,100	655.8
1960 - 1974	-5,554,000	1,869,200	-3,684,800	-263,200	203.6
1974 - 1988	-3,836,000	2,972,200	-863,800	-61,700	106.5
1988 – 2000[a]	-4,062,600[a]	2,112,600	-1,950,000[a]	-162,500[a]	125.3
1936 - 2000	**-19,652,600**	**6,954,000**	**-12,698,600**	**-198,415**	******

[a] Estimated changes (see paragraph 4.3)

4.4. The volume of material in the ebb tide delta of Beaufort Inlet has decreased significantly, particularly since 1952. While the ebb tide delta has decreased in volume, the surface area of the delta has actually increased, particularly in a seaward direction. Changes in the surface area of the ebb tide delta of Beaufort Inlet and the general configuration of the bar between 1839 and 1974 are shown on Figure 4.2. For comparative purposes, the 30-foot mlw depth contour for the 1974 survey has been superimposed on the other surveys.

4.5. The seaward growth and reshaping of the ebb tide delta began with the deepening of the project to 30-feet mlw in 1936. Following this deepening operation, subsequent channel maintenance was performed along a fixed channel alignment. By 1952, the planform of the ebb tide delta had changed from its pre-project bulbous configuration to a more deltaic shape. During the 1936 to 1952 time period, the ebb tide delta actually increased in volume, however, the increased volume was associated with the reshaping of the delta in which the areas immediately adjacent to and seaward of the bar channel increased in volume while the east and west flanks of the delta lost material resulting in increased depths over these areas. Between 1952 and 1960, the ebb tide delta of Beaufort Inlet lost over 9 million cubic yards, which resulted in significant deepening of the delta. Even though the depths over the ebb tide delta increased during this period, the delta continued to grow in a seaward direction. Since 1960, the erosion or deflation of the ebb tide delta has continued at a fairly steady rate, as has the seaward extension of the delta.

4.6. The seaward extension of the ebb tide delta occurred as a result of the yearly repetition of maintenance dredging along a fixed channel alignment. The following sequence of events explains how this occurred. The deepening of the bar channel resulted in a concentration of ebb tidal currents over greater distances through the ebb tide delta than under natural conditions. As ebb velocities dissipated at the seaward end of the bar channel, material transport would cease and the material being transported by the ebb currents would settle to the bottom. Since flood currents are not strong enough in this area to move the deposited material bayward, the material deposited during the ebb cycle would form a new shoal. During the next maintenance operation, the bar channel would be extended through this newly formed shoal and in effect increase the length of the bar channel. Since the entire new shoal was not removed by the maintenance operation, the residual shoal material formed a seaward extension of the ebb tide delta. This process has been repeated almost yearly since 1936 resulting in the present ebb tide delta and bar channel configuration. Note that the slight shift in the location and orientation of the ocean bar channel accomplished in 1978 during the construction of the 40-foot mlw project did not significantly change the location of the seaward end of the bar channel.

4.7. Maintenance of the ocean entrance channel through Beaufort Inlet has also eliminated the movement of the inlet channel from one side of the inlet to the other. As shown on Figure 4.2, the ocean bar channel orientation tended to fluctuate between a southeasterly alignment and a slightly south-southwesterly alignment prior to 1936. This movement of the ocean bar channel was an important mechanism with regard to natural sediment bypassing. During periods in which the channel was aligned in a southeasterly direction (1839 to around 1885) a considerable amount of littoral material was transported toward Shackleford Banks. Also, at the seaward end of the channel, a large lobe of sand would form just seaward of the Shackleford Banks shoreline. This channel alignment provided some protection to the west end of Shackleford Banks as the ebb tide delta tended to act like a submerged offshore breakwater, greatly reducing the amount of wave energy reaching the west end of Shackleford Banks. On the other hand, the proximity of the channel to Shackleford Point prevented Shackleford Banks from migrating into the inlet. When the channel shifted to a more south-southeasterly alignment, the lobe of sand off Shackleford Banks was driven onto the beach, eventually welding to the shoreline, thus providing a large quantity of littoral sediment to the island. As the channel continued to migrate to the southwest (see the 1927 survey on Figure 4.2) the bar channel and ebb tide delta provided the same kind of benefit to Bogue Banks that the southeasterly channel alignment provided to Shackleford Banks. If the ocean bar channel had not been modified in 1936 with the construction of the 30-foot mlw channel, the bar channel would have likely migrated back to a southeasterly alignment and the process begun anew. The elimination of the natural movement of the ocean bar channel greatly reduced the ability of Beaufort Inlet to naturally bypass littoral sediment from Bogue Banks to Shackleford Banks and vise versa. Also, the fixed location of the bar channel allowed Shackleford Point to migrate to the west and in the process, store a large volume of littoral sediment that would have otherwise remained in the active littoral zone. Between 1936 and 1974, the west end of Shackleford Banks migrated approximately 5,000 feet to the west with the width of the accreted area averaging about 3,500 feet (see Figure 4.2). The estimated volume of littoral sediment contained within this accreted area is 6,500,000 cubic yards. Shackeford Point has remained relatively stable since 1974 as the strong tidal currents flowing through the inlet gorge combined with the annual maintenance dredging, has prevented any additional westward movement of the point.

4.8. Impact of Storms on the Ebb Tide Delta. While channel improvements and the associated annual maintenance dredging has contributed significantly to the reshaping and deflation of the Beaufort Inlet ebb tide delta and the seaward extension of the bar channel, other factors such as coastal storms have also impacted the delta and the movement of material across the inlet. In this regard, the greatest volume loss from the ebb tide delta occurred during the 1952 to 1960 time interval during which the Beaufort Inlet area was impacted by several hurricanes including Hurricane Hazel in 1954, Hurricanes Connie, Diane, and Ione in 1955, Hurricane Helene in 1958, and Hurricane Donna in 1960. Hurricane Donna remains the storm of record in the study area, producing a maximum still water level of 10.6 feet above msl.

4.9. Under normal tide and wave conditions, waves undergo a rather high degree of refraction around the ebb tide delta of an inlet resulting in the near shore wave energy being directed toward the inlet from both sides regardless of the original deepwater wave direction. Figure 4.3(a) shows a generalized wave refraction pattern around a typical ebb tide delta under normal conditions. During storms in which the water levels over the delta are deeper than normal, wave refraction does not occur to the same degree. A schematic sketch of a generalized wave refraction pattern around an inlet ebb tide delta during a storm is shown on Figure 4.3(b). The higher tides and corresponding deeper depths over the ebb tide delta during the storm permits an inordinate amount of wave energy to attack the bar, setting into motion large volumes of delta material that is transported in the direction of the waves. As a result, during a storm, the ebb tide delta of an inlet appears to serve as a source of sediment for the adjacent beaches, particularly the beaches downdrift of the storm wave direction, whereas, under normal wave and tide conditions, the delta acts as a sediment sink. The combination of storm activity on the ebb tide delta and the ability of the ocean bar channel to migrate from one side of the inlet to the other are the two major processes associated with natural sediment bypassing around an inlet.

4.10. Storm History versus Ebb Tide Delta Volume Changes (Storm Intensity Factor). The analysis of storm activity that has affected the study area focused on tropical storm events as information on these storms is readily available. Extratropical events, commonly known as "nor'easters", are known to have a significant impact on the area. However, the tropical events provide a relative comparison of storm conditions that have affected the area during various time periods and should serve as a reasonable proxy for storm activity.

4.11. The history of tropical storms that have affected the project area was obtained from the UNISIYS web site (http://weather.unisys.com/hurricane/atlantic/index.html), which provides storm track data for the period 1886 to 1998 courtesy of Colorado State University. The storm tracks give the latitude and longitude of the storms every 6 hours along with an estimate of the wind speed and the storm classification, i.e., whether the storm is a class 1 to 5 hurricane, a tropical storm, etc. The latitude and longitude positions of the storm were used to determine the distance the eye of the storm or center of low pressure passed by Morehead City and the relative position of the storm, i.e., if it passed to the southwest, south, southeast, east, northeast, north, or northwest or directly over (i.e. within 50 miles) Morehead City. Based on these storm statistics, a relative storm intensity factor (SIF) was computed for each event. The storm intensity factor was computed by the following:

$$SIF = (V^2/d) \times P$$

where:

SIF = Storm Intensity Factor
V = Storm wind velocity
d = Distance from the center of storm circulation to Morehead City
P = Storm position factor: (= 2.0 for storms passing South and Southwest and within 50 miles of Morehead City, = 1.5 for storms passing North and Northwest of Morehead City, and = 1 .0 for storms passing East and Northeast of Morehead City).

Note that storm duration is an important factor with respect to the potential impacts of a storm on an area, particularly on the area beaches, however, storm duration is more of a factor with respect to slow moving extratropical events, which can persist for days. In the case of tropical events, these fast moving systems generally have their maximum impact of an area over a period of hours. Therefore, storm duration was not included in the storm intensity factor.

4.12. The relative significance of the storm position factor is that storms passing to the south and southwest or directly over Morehead City (i.e., within 50 miles) would have a greater impact on the study area due to the counterclockwise wind circulation around the center of the storm that would direct winds onshore. Storms passing to the north and northwest would produce winds blowing generally parallel to the shoreline to slightly onshore and would have less of an impact on the study area. Finally, storms passing to the east and northeast would produce offshore winds in the study area and would have the smallest impact on the area beaches. Computation of the storm intensity factor for all of the storms included in the analysis is presented in Appendix C. The individual storm intensity factors for storms occurring within the ebb tide delta survey intervals given above (i.e., 1862 to 1936, 1936 to 1952, 1952 to 1960, 1960 to 1974, and 1974 to 1988) were summed and an average annual storm intensity factor computed for each time period. The average annual storm intensity factor was also determined for the 1988 to 2000 time period even though the ebb tide delta volume change was only estimated for this period. The resulting average annual storm intensities for the various time periods are given in Table 4.1. A plot of the average annual storm intensity factor for each survey period versus the average annual change in the volume of material on the Beaufort Inlet ebb tide delta outside the immediate area of the bar channel, shown on Figure 4.4, indicates an extremely good correlation between the average annual storm intensity factor and the annual rate of ebb tide delta volume change. This result tends to support the important role storms play on inlet ebb tide deltas. The data point for the 1988 to 2000

time period is shown on this figure, however, it was not used to compute the trend line. Even so, the 1988 to 2000 data point falls very close to the trend line.
4.13. The apparent relationship between the change in the volume of material on the ebb tide delta and storm activity has been observed at other inlets in North Carolina, namely, Oregon Inlet (U.S. Army Corps of Engineers, 1980), which is northernmost inlet on the North Carolina coast, and Lockwoods Folly Inlet (U.S. Army Corps of Engineers, 1974), located approximately midway between Cape Fear and the North Carolina/South Carolina State line. The major difference in the behavior of these two inlets, however, is that there appeared to be significant recovery of the ebb tide deltas following the periods of intense storm activity. That is, the volume of material on the ebb tide delta of these two inlets seemed to fluctuate around quasi-equilibrium volumes. This has not been the case for the Beaufort Inlet ebb tide delta as the volume of material on the ebb tide delta has continued to decrease even during periods of relatively low storm activity.

4.14. The deviation of the behavior of the Beaufort Inlet ebb tide delta from other inlets in North Carolina is significant in that the ebb tide delta has become a significant source of shoal material for the entrance channel and inner harbor as well. The deep ocean entrance channel through the Beaufort Inlet ebb tide delta collects any ebb tide shoal material set in motion by wave and tide action under normal and storm conditions. The channel also intercepts littoral materials transported to the inlet from the adjacent beaches. Once the material deposits in the entrance channel, it cannot escape the channel by natural processes. Rather, it is removed and deposited offshore during each maintenance operation. The volume of littoral material removed annually from the Beaufort Inlet entrance channel and inner portion of the Morehead City Harbor exceeds the annual rate of longshore transport moving into the inlet. With the amount of material being removed from the inlet system by dredging exceeding the rate of supply, the expected result would be the deflation or erosion of the ebb tide delta.

4.15. Changes in Tidal Flow through Beaufort Inlet. Direct measurements of tidal flow or tidal prism through Beaufort Inlet have been limited to observations made August 1935 and October 1936. Note that the tidal prism of an inlet is defined as the total volume of water passing though the inlet during a complete ebb or flood tidal phase. NOS did conduct tidal current surveys in 1960; however, the measurements were not sufficient for use in computation of the tidal prism. An attempt was also made in 1974 to measure flows through the inlet, but the effort was abandoned due to severe weather. While there are not a sufficient number of direct measurements of the tidal prism to determine if the flow through Beaufort Inlet has increased in response to harbor improvements, an indirect measure of the tidal prism can be obtained by comparing changes in the inlet's cross-sectional area. O'Brien (1969) discovered a strong relationship between the minimum cross-sectional area of an inlet (measured at mean sea level) and its spring tidal prism, that is the volume of water passing through the inlet during a normal spring tide event. Most of the inlets included in O'Brien's earlier work focused on inlets on the West Coast of the United States. Jarrett (1976) developed refinements in this functional relationship by considering inlets on the Atlantic, Gulf, and West Coast of the U.S. as well as whether the inlets were stabilized with one jetty, two jetties, or not stabilized by structures. The form of this relationship is:

$$A=\alpha P^n$$

where:

A = cross-sectional area (square feet) of the inlet throat measured below mean sea level;

α = empirical coefficient;

P = spring tidal prism (cubic feet) = volume of water passing through the inlet during a spring tide (ebb or flood, which ever is greater);

n = empirical coefficient.

The values for the empirical coefficients α and n for unjettied or single jettied inlets on the Atlantic Coast were determined by Jarrett to be 5.37×10^{-6} and 1.07 respectively. Thus the relationship between A and P for east coast single jettied and unjettied inlets is:

$$A = 5.37 \times 10^{-6} P^{1.07}$$

Rearranging this relationship, the tidal prism of an inlet can be computed from a known cross-sectional area by the following:

$$P = 8.42 \times 10^{4} A^{0.93}$$

Historic cross-sectional areas and the associated tidal prisms for Beaufort Inlet are given in Table 4.2.

4.16. As is evident for the data provided in Table 4.2, the cross-sectional area and associated tidal prism of Beaufort Inlet has remained fairly stable between 1936 and 1974. This method of estimating the tidal prism of an inlet does not take into account the flow carrying efficiency of the channel. Channels with large cross-sectional areas but characterized by shallow over bank areas, would offer a higher degree of resistance to flow than a deep narrow channel having the same cross-sectional area. The tidal prism-inlet cross-sectional area relationship does not account for this, as both cross-sections would have the same indicated tidal prism. In any event, based on the cross-sectionals areas of Beaufort Inlet over time and the implied tidal prism associated with these inlet cross-sectional areas, the tidal prism of Beaufort Inlet has apparently not been significantly altered by the various harbor improvement projects.

Table 4.2
Cross-Sectional Areas and Tidal Prisms for Beaufort Inlet (1862 to 1974)

Date of Survey	Inlet cross-sectional area @ msl (sq. ft.)	Spring tidal prism (cu. ft.)
1862	129,600	5.05×10^9
1908	92,200	3.67×10^9
1936	86,500	3.46×10^9
1952	75,600	3.05×10^9
1960	74,800	3.02×10^9

Figure 4.1 Bounda
Used to Determine
the Ebb Tide Delta

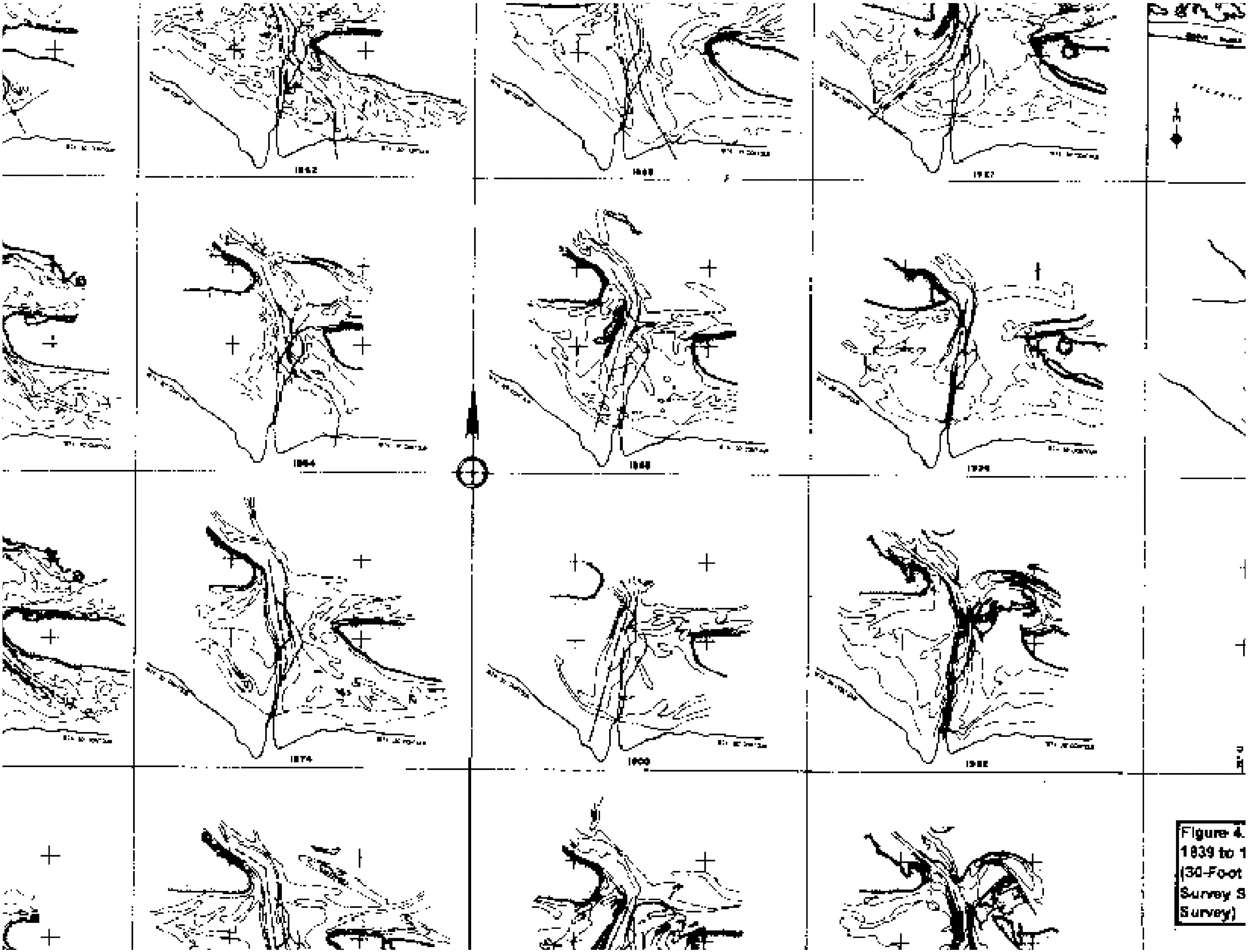


Figure 4.
1839 to 1
(30-Foot
Survey S
Survey)

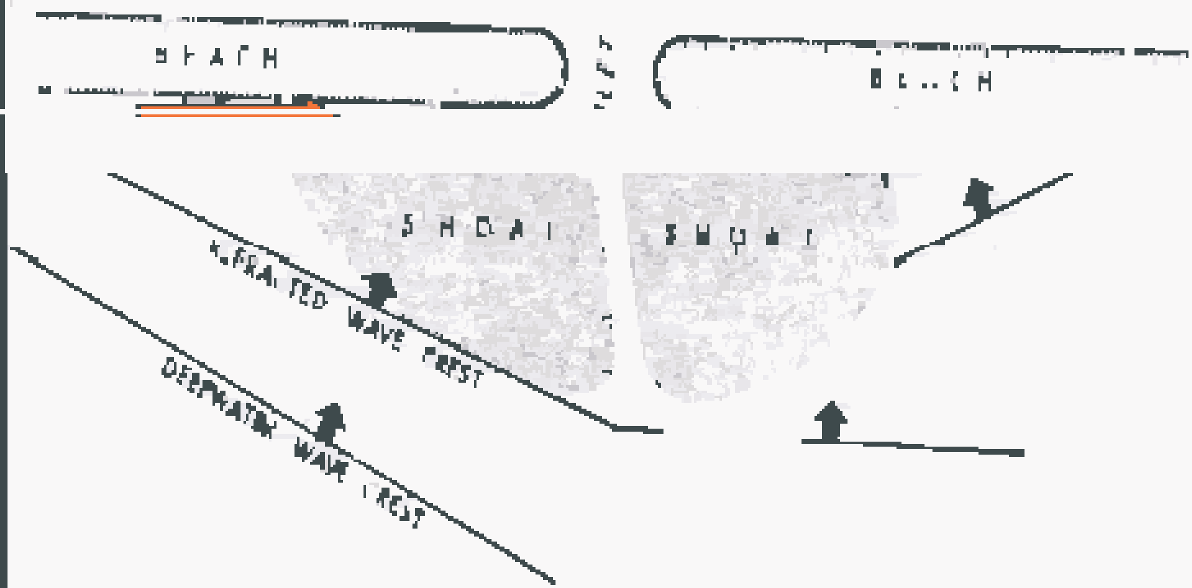


Figure 4.3(a)
Generalized Wave Pattern at an
Inlet Under Normal Conditions

Littoral Current Direction

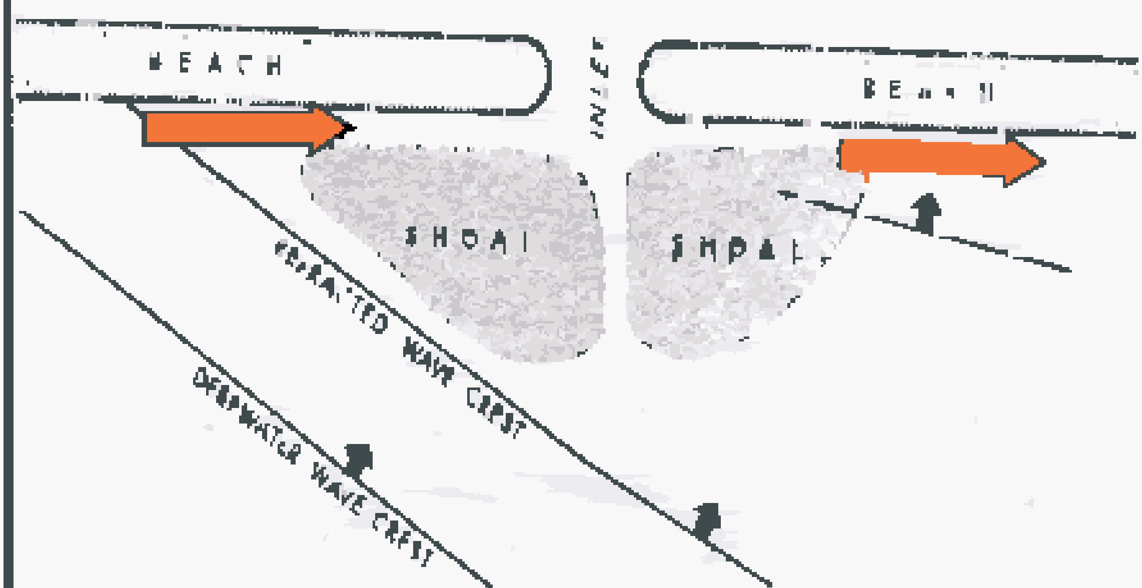
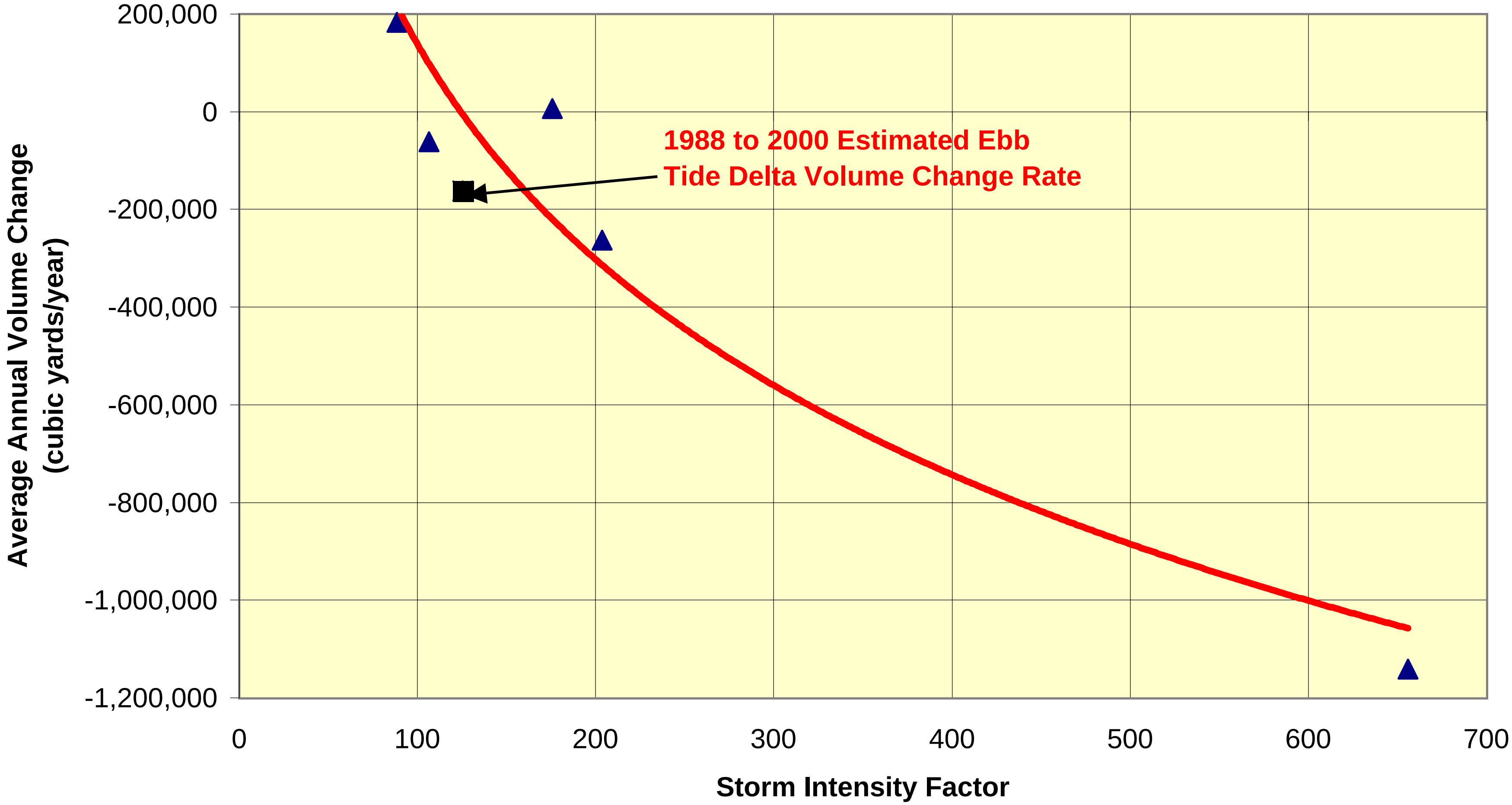


Figure 4.3(b)
Generalized Wave Pattern at an
Inlet Under Storm Conditions

Figure 4.4 Average Annual Storm Intensity Factor versus Average Annual Change in the Ebb Tide Delta Volume of Beaufort Inlet



NC Storms
SIF vs Bar change MHC
fig 4.4

1974	80,500	3.24×10^9

5.0 GENERALIZED SEDIMENT BUDGET

5.1. Generalized Assessment of Harbor Maintenance Dredging on the Sediment Budget of the Area. A generalized assessment was made to determine the amount of littoral sediment removed from the sand sharing system of Beaufort Inlet, Bogue Banks, and Shackleford Banks as a result of the construction and maintenance of the Morehead City Harbor project since 1936. Quantities in the generalized assessment include: (1) the change in the volume of sediment on the ebb tide delta; (2) the amount of material removed from the inlet bar channel during construction and maintenance of the various channel dimensions; (3) maintenance dredging in the inner harbor; (4) sediment accumulation on Shackleford Point; and (5) the volume of littoral material returned to the beach system by the three beach disposal operations.

5.2. Ebb Tide Delta Volume Changes. The total estimated volume change on the ebb tide delta of Beaufort Inlet between 1936 and 2000 is 19,652,600 cubic yards as reported in Table 4.1. This total volume change on the ebb tide delta includes material removed from the ocean bar channel to construct the 35-, 42-, and 47-foot mlw entrance channels in 1961, 1978, and 1994, respectively. The combined total of all new work dredging in the entrance channel for these three harbor improvement increments was 6,954,000 cubic yards (see Table 4.1). All of this new work material was deposited in the ODMDS, which is outside the active littoral zone. Subtracting this new work volume from the total ebb tide delta volume change results in an estimate of the amount of material removed from the portions of the ebb tide delta located east and west of the bar channel, i.e., sediment removed from the delta by wave and tidal current action. This difference is 12,698,600 cubic yards.

5.3. Entrance Channel Maintenance. The annual amount of maintenance dredging performed in the ocean entrance channel since 1936 is provided in Table B-1 of Appendix B and totals approximately 38,043,100 cubic yards. Most of this maintenance material was deposited in the ODMDS. An estimated 1,000,000 cubic yards was placed in near shore sites located west of the inlet, however, the material deposited in these near shore sites has not moved and is consider to have been removed from the active littoral zone. Based on the compatibility analysis between the size characteristics of the ocean bar channel shoal material and the native beach material provided in paragraph 3.9, 86 percent of the shoal material is believed to be littoral or beach material. Thus, the estimated total volume of littoral sediment removed by maintenance dredging in the ocean bar channel of Beaufort Inlet between 1936 and 2000 has been 32,717,100 cubic yards *(= 38,043,100 x 0.86).*

5.4. Inner Harbor Maintenance. The volume of material removed to construct the various harbor improvement increments in the inner harbor did not have a direct impact on the overall sediment budget of the area. However, the deep inner basins provide sediment traps for material transported into the inlet from the ocean as well as for river and estuarine sediments. Between 1936 and 2000, a total of about 9,544,000 cubic yards of material has been removed from the inner harbor by maintenance dredging. The compatibility analysis for the inner harbor shoal material, given in paragraph 3.8, found that only 69 percent of the material is compatible with the native beach sand. Accordingly, the estimated volume of littoral sediment dredged from the inner harbor during maintenance operations between 1936 and 2000 is 6,585,400 cubic yards.

5.5. Shackleford Point. Material that has accumulated to form the sand spit on the west end of Shackleford Banks between 1936 and 1974 is material that would have normally remained within the active littoral system with most of the material available to move either back on to Shackleford Banks or cross over the inlet and onto Bogue Banks. However, the changes in the natural inlet process associated with the maintenance of the ocean bar channel along a fixed alignment prevented this material from moving out of the inlet complex and in essence, became part of the inlet shoal system. As noted in paragraph 4.7, the estimated volume of littoral material contained in the westward extension of Shackleford Banks is 6,500,000 cubic yards.

5.6. Beach Disposal Operations. The total amount of material pumped to the east end of Bogue Banks, including the Fort Macon State Park shoreline and the Atlantic Beach shoreline, totals 10,012,600. This total volume includes 1,178,600 cubic yards pumped to Fort Macon in 1978 during the construction of the 40-foot project, 4,168,600 pumped to Atlantic Beach during the 1986 Brandt Island pump-out operation, and a total of 4,664,400 pumped to Fort Macon and Atlantic Beach in 1994 as part of a combined operation involving the construction of the 45-foot project, maintenance of the inner harbor, and the pump-out of Brandt Island. Based on the compatibility analysis of the inner harbor shoal material, 69 percent of this material was littoral sand. Therefore, the net fill provided by these three operations was 6,908,700 cubic yards. As discussed later in Section 7 of this report, a considerable volume of this deposited material is believed to have rapidly returned back to Beaufort Inlet, resulting in no long-lasting net benefit to the sediment budget of the east end of Bogue Banks. For the moment, however, this is ignored in the development of the generalized sediment budget.

5.7. Summary of Generalized Assessment. The volume changes and dredging quantities associated with the Morehead City Harbor project since 1936, discussed above, are summarized in Table 5.1. The total volume of littoral sediment removed from the littoral system by maintenance dredging in the ocean bar channel, sediment accumulation on the west end of Shackleford Banks, and maintenance dredging in the inner harbor totals 45,802,500 cubic yards. The beach disposal operations carried out in 1978, 1986, and 1994 returned 6,908,700 cubic yards of littoral sediment to the beaches on Bogue Banks resulting in a net loss of sediment to the system of 38,893,800 cubic yards. The volume of material eroded from the east and west portions of the ebb tide delta of Beaufort Inlet (i.e., outside the immediate area of the bar channel) is assumed to be part of the sediment removed during maintenance of the bar channel or the inner harbor. Based on this assumption, the net loss of sediment from the littoral systems of Bogue Banks and Shackleford Banks has been 26,195,200 cubic yards during the 64-year period from 1936 to 2000. This is equivalent to an annual rate of littoral sediment removal from the system of 409,300 cubic yards/year.

Table 5.1
Estimate of the Net Loss of Littoral Sediment from the Littoral System due to
The Morehead City Harbor Project

Factor Contributing to Sediment Loss or Gain in the Littoral System (1936-2000)	Volume (cubic yards)
Total Change in Ebb Tide Delta Volume	19,652,600
Volume of New Work Dredging in Bar Channel	-6,954,000
Ebb Tide Delta Volume Change East and West of Channel	**12,698,600**
Ocean Side of Beaufort Inlet	
Littoral Material Removed from the Bar Channel During Maintenance Dredging	-32,717,100
Material Contained in the West Extension of Shackleford Banks	-6,500,000
Total Volume Littoral Sediment Removed from System by Maintenance Dredging and Shackleford Banks	**-39,217,100**
Inner Harbor	
Littoral Material Removed from the Inner Harbor during maintenance dredging	**-6,585,400**
Total Volume of Littoral Sediment Removed by the Ocean Side of Beaufort Inlet and the Inner Harbor	**-45,802,500**
Volume of Littoral Material Returned to the Beach by the Beach Disposal Operations	**6,908,700**
Net Volume of Littoral Sediment Removed from the System as a Result of the Morehead City Harbor Project	**-38,893,800**
Shoal Volume Contributed by the Ebb Tide Delta Deflation	**12,698,600**
Net Loss Littoral Sediment from the System	**-26,195,200**
Equivalent Annual Rate of Littoral Sediment Removal	**409,300 cy/yr**

6.0 PRIOR IMPACT ASSESSMENTS

6.1. Impact Assessment Studies. Evaluations of the possible impacts of the Morehead City Harbor project on the adjacent shorelines have been conducted on two separate occasions by employing sediment budget techniques. The first analysis was presented in the 1976 GDM for the 40-foot mlw project. The second sediment budget analysis was conducted during the feasibility phase of the 45-foot project (U.S. Army Corps of Engineers, 1990). Summaries of the finding of these two analyses are provided below.

6.2 Sediment Budget Analysis-1976 GDM. The sediment budget analysis, contained in the 1976 GDM, combined the results of a wave transformation/wave energy analysis and measured or estimated volume changes on portions of Bogue Banks; all of Shackleford Banks; and in Beaufort Inlet (including the inner harbor the adjoining sounds) to determine sediment transport rates into and out of each coastal unit. The analysis considered 5 different time periods in an attempt to determine the changes in transport patterns caused by the Morehead City Harbor project.

6.3. One of the key elements in any sediment budget/sand transport analysis is the quality of the wave data used to determine littoral sediment transport potential and directions. In the case of the 1976 analysis, the wave data used consisted of visual wave observations made from ships passing offshore of the Morehead City-Bogue Banks area. At the time the analysis was performed, this ship data was the best wave data available in terms of combined observations of wave directions, periods, and heights. As shown on Figure 1.2, the study area is located west of Cape Lookout and is shielded from attack by waves approaching from the west clockwise around to the northeast. Furthermore, waves approaching from the east and east-southeast are partially blocked by the shoals of Cape Lookout. As a result, the study area receives the largest percentage of wave energy from the southeast clockwise around to the west-southwest directions. Of these directions, the ship observation data indicated that the greatest amount of wave energy originates out of the southwest and west-southwest directions, tending to cause littoral sediment transport from west to east along the study area shorelines. The results of the 1976 sediment budget analysis for the 5 time periods are provided in Table 6.1. A brief summary of the more pertinent results of this sediment budget analysis is given below.

Table 6.1
Results of the 1976 Sediment Budget Analysis

Time Period	East Transport Bogue Banks (cy/yr)	West Trans. Shackleford Banks (cy/yr)	By-Passing to the East (cy/yr)	By-Passing to the West (cy/yr)
1854-1936	702,000	239,000	492,000	133,000
1936-1952	1,720,000	584,000	1,241,000	234,000
1952-1960	-400,000(1)	-136,000(1)	-518,000(2)	88,000
1960-1974	641,000	218,000	238,000	121,000
1936-1974	378,000	128,000	60,000	-66,000(2)

Notes: (1) Negative transport quantities indicate drift moving in opposite direction from assumed.
(2) Negative bypassing quantities indicate transport into the inlet possibly by tidal currents.

6.4. Summary of 1976 Sediment Budget Results. According to the 1976 GDM, the 1854 to 1936 time period was determined to be the best indicator of sand transport characteristics in the area prior to major harbor improvements while the 1960 to 1974 period was judged to be indicative of with-project conditions. Comparison of the sediment transport quantities during these two time periods resulted in the following conclusions:

(a) Sediment transport in the vicinity of Beaufort Inlet is predominantly to the east with 74.6 % of the sand transport moving in that direction and 25.4 % moving to the west.

(b) The predominant transport direction was supported by shoaling patterns in the inlet bar channel in which 68 % of the shoaling occurred on the west side of the channel next to Bogue Banks.

(c) Sediment bypassing from Bogue Banks to Shackleford Banks prior to major harbor improvements represented about 52 % of the gross drift in the vicinity of the inlet. The percentage of the gross drift bypassing to Shackleford Banks during the 1960-1974 with project condition decreased to 28 %. (Note: Gross drift is the sum of the sand transport volumes moving into the inlet from both the east and west directions, i.e., from Bogue Banks and Shackleford Banks respectively.)

(d) Sediment by-passing from Shackleford Banks to Bogue Banks during the pre-project time period and the 1960-1974 with-project period was about 14 % of the gross littoral drift for both time periods.

6.5. Based on these results, the Morehead City Harbor project appeared to be having the greatest impact on Shackleford Banks. Therefore, consideration was given in the 1976 GDM to mechanically bypass some of the Beaufort Inlet maintenance material to Shackleford Banks. However, this proposal was not accepted by the National Park Service, which controls Shackleford Banks as part of the Cape Lookout National Seashore. While no mechanical bypassing was included in the 40-foot mlw project, a beach profile-monitoring program was established following the 1978-deepening project. This monitoring program consists of annual beach profiles taken at approximately 2,000-foot intervals along the entire length of Shackleford Banks and 1000-foot intervals along the eastern 6.5 miles of Bogue Banks.

6.6. In addition to the possible impacts of the project on Shackleford Banks, the 40-foot project sediment budget analysis found that the ebb tide delta of Beaufort Inlet had lost 14,683,000 cubic yards of material between 1952 and 1974. This is equal to a rate of delta deflation of 667,400 cubic yards/year. The delta deflation was attributed to the removal of sediment from Beaufort Inlet by the hopper dredge maintenance activity and the natural by-passing of sediment around the inlet, the total of which exceeds the annual gross rate of littoral sand transport to the inlet.

6.7. Sediment Budget Analysis-1990 Feasibility Report. The sediment budget analysis performed for the 1990 feasibility report for the Morehead City Harbor project concentrated on the 1980 to 1988 time period during which the 40-foot mlw project was being maintained. Shoreline change information used for the sediment budget analysis over this period consisted of the beach profile data acquired through the beach-monitoring program established following the construction of the 40-foot project. This beach profile survey data indicated that Bogue Banks experienced net accretion during the 8-year analysis period, primarily as a result of the 1986 beach disposal operation. However, Shackleford Banks, which did not receive any artificial nourishment during this period, also experienced net accretion.

6.8. The general approach used in the 1990 analysis was the same as the 1976 analysis except a more reliable set of wave information was used compared to that used for the 1976 sediment budget analysis. Specifically, the 1990 analysis used Phase II wave information developed by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) from a 20-year hindcast of wave conditions for the period 1956 to 1975 inclusive (Waterways Experiment Station, 1982). The wave characteristics represented by the Phase II wave information are for offshore locations that are in relatively deep water. This offshore wave information was transformed to the shoreline using a wave transformation model known as RCPWAVE, which was also developed by WES. The 1990 sediment budget analysis results are given in Table 6.2.

Table 6.2
Results of the 1990 Sediment Budget Analysis

Time Period	Easterly Sand Transport frm Bogue Banks (cy/yr)	Westerly Sand Trans. frm Shackleford Banks (cy/yr)	By-Passing to the East (cy/yr)	By-Passing to the West (cy/yr)
1980-1988	1,130,000	328,000	898,000	-113,000[1]

(1) Negative bypassing quantities indicate transport into the inlet possibly by tidal currents.

6.9. Summary of 1990 Sediment Budget Results. The gross sand transport rates, that is the sum of the easterly transport off Bogue Banks and the westerly transport off Shackleford Banks, computed for the 1980-1988 period was approximately 600,000 cubic yards/year greater than the gross transport rate computed for the 1960 to 1974 period in the 1976 GDM. The higher transport rates for the 1990 analysis may be due to the difference in the quality of the wave information. In the case of the 1976 analysis, the ship observations were probably biased toward smaller wave heights since ships would normally avoid areas being affected by storms or high waves. In any event, the distribution of sand transport to the east and west obtained from these two independent analyses were essentially the same as the 1990 analysis indicated that 77.5 % of the gross transport at the inlet is to the east compared to 74.6 % obtained from the 1976 analysis.

6.10. Another major finding of the 1990 analysis was the apparent high rate of sand bypassing from Beaufort Inlet toward Shackleford Banks (computed to be about 61.6 % of the gross sediment transport) and no sediment bypassing from the inlet toward Bogue Banks. In fact, the negative sign shown for the sediment bypassing from the inlet toward Bogue Banks is an indication of sediment actually moving from Bogue Banks into the inlet, possibly as a result of tidal currents. While no natural sediment by-passing from the inlet to Bogue Banks was computed for the 1980 to 1988 time period, 4,168,600 cubic yards of dredged material was placed on Bogue Banks in 1986 from maintenance dredging in the inner harbor and the removal of material from the Brandt Island disposal area. This volume of dredged material is equivalent to an annual rate over the 8 year analysis period of 521,000 cubic yards/year, which is almost 4 times the natural rate of sediment bypassing from Shackleford Banks to Bogue Banks computed for the 1854 to 1936 pre-project period.

7.0 ANALYSIS OF PROJECT IMPACTS ON ADJACENT SHORELINES

7.1. General. The evaluation of the impacts of the Morehead City Harbor project on the shorelines of Bogue Banks and Shackleford Banks includes: (a) an assessment of the changes in wave transformation and associated longshore sediment transport potential resulting from the reconfiguration of the ebb tide delta of Beaufort Inlet and the disposal of dredged material in the ODMDS; (b) an analysis of shoreline changes on Bogue Banks and Shackleford Banks for the pre-project and with-project time periods; and (c) an evaluation of the performance of the three beach disposal operations on Bogue Banks. Improvements for the Morehead City Harbor project began in 1911 with the construction of the 20-foot mlw x 300-foot wide ocean entrance channel. This channel was maintained with minimal maintenance dredging until 1935. Major modification to the harbor project began in 1936 with the deepening and widening of the entrance channel to a depth of 30 feet mlw at a width of 400 feet and construction of the interior basins and connecting channels to a depth of 30 feet mlw. Subsequent harbor improvements occurred in 1961, 1978, and 1994 culminating in the present project dimensions consisting of a 47-foot deep entrance channel and 45-foot deep interior basins and connecting channels. Due to the relatively minor nature of the harbor improvements prior to 1936, the time period from the mid-1800's to 1936 is designated as the pre-project period.

7.2. The operation and maintenance of the harbor project was modified with the construction of the 40-foot project in 1978 to include periodic disposal of the Brandt Island maintenance material on the east end of Bogue Banks. Specifically, the Brandt Island confined material disposal site was to be used as a storage facility for a period of 8 to 10 years after which, the stored material would be removed and deposited on a designated beach disposal area extending 7 miles west of Beaufort Inlet. This process would allow Brandt Island to serve as a perpetual disposal site for the life of the project and would not require additional upland sites that would damage or destroy valuable wetland and upland areas. The beach disposal area includes the shoreline fronting the Fort Macon State Park, the Town of Atlantic Beach, and the eastern one-mile segment of the Town of Pine Knoll Shores. To date, material stored on Brandt Island has been removed on two occasions (1986 and 1994). In addition, material removed to construct the inner portion of the 40-foot project in 1978 was deposited on the shoreline fronting the Fort Macon State Park. These beach disposal operations, particularly the disposal of material from Brandt Island on the east end of Bogue Banks, has been an integral part of the Morehead City Harbor project operations and maintenance since 1978 and its impacts on the receiving and adjacent shorelines must be included in the overall assessment of the impact of the harbor project.

7.3. Wave Transformation/Sediment Transport Potential. An analysis of the changes in wave patterns and longshore sediment transport potential associated with the offshore bathymetry changes caused by the construction and maintenance of the Morehead City Harbor project was performed using wave transformation techniques. The major changes in the offshore bathymetry included the reconfiguration of the ebb tide delta of Beaufort

Inlet and the creation of the offshore mound (ODMDS) resulting from 64 years of ocean disposal of the ocean bar channel construction and maintenance material. This was accomplished by performing the wave transformation analysis using bathymetry representing existing conditions and comparing the results with those obtained using bathymetry representing the pre-project condition. The bathymetry of the area is very complex and includes the shoal extending seaward from Cape Lookout, which partially blocks wave energy approaching the area from the east and southeast direction, the ebb tide delta of Beaufort Inlet, and the ODMDS. The analysis does not take into account the impacts of tidal currents on wave transformation and does not adequately represent wave breaking and subsequent reformation of waves as they move across shallow areas such as the Cape Lookout Shoals and the ebb tide delta of Beaufort Inlet. These limitations result in computational instabilities, particularly along the shorelines immediately east and west of Beaufort Inlet. Accordingly, interpretation of the theoretical results in these areas must be viewed with caution. However, the wave transformation analysis for the existing and pre-project bathymetry was conducted in the same manner using identical wave conditions, which provided a reasonable relative comparison of the impacts of the bathymetry changes on sediment transport potential in the area. In this regard, the numerical results cannot be interpreted as representing absolute changes in sediment transport potential (i.e. the magnitude of longshore sediment transport), rather, the results are only indicative of possible trends in sediment transport potential associated with the changes in offshore bathymetry caused by the harbor project.

7.4. The Wilmington District contracted with the engineering consulting firm of Dames and Moore to perform a wave transformation/sediment transport potential evaluation of the study area. During the course of this investigation, Dames and Moore merged with URS Corporation. URS was charged with the task of transforming waves over the complex bathymetry associated with the Cape Lookout shoals and the shoals associated with Beaufort Inlet. The task order called for two sets of wave transformation analysis. The first wave transformation analysis was performed for existing bathymetric condition, including the existing ebb tide delta configuration of Beaufort Inlet and the ODMDS, the offshore sediment mounds created by disposal of material removed from Beaufort Inlet during construction and maintenance of the Beaufort Inlet entrance channel. The ODMDS is a significant bathymetric feature located southwest of the entrance channel, as shown on Figure 2.2. The disposal mounds rise between 10 and 25 feet above the natural ocean bottom in the area. The second condition used 1862 inlet bathymetry and a smoothed offshore bottom in the vicinity of the ODMDS to represent pre-project conditions. The bathymetry used to represent existing conditions is shown on Figure 7.1 with the 1862 bathymetry given on Figure 7.2. The area covered by the 1862 inlet survey that was superimposed on the existing bathymetry to create the 1862 condition is outlined on Figure 7.2.

7.5. Wave Information. Previous wave transformation analyses preformed for the Morehead City Harbor project, discussed in Section 6 of this report, used wave observations from ships passing offshore of Morehead City (1976 GDM) and wave statistics developed by the Waterways Experiment Station (WES) in 1982 by using wave hindcasting techniques (1990 Feasibility Study). The wave hindcast procedures used in

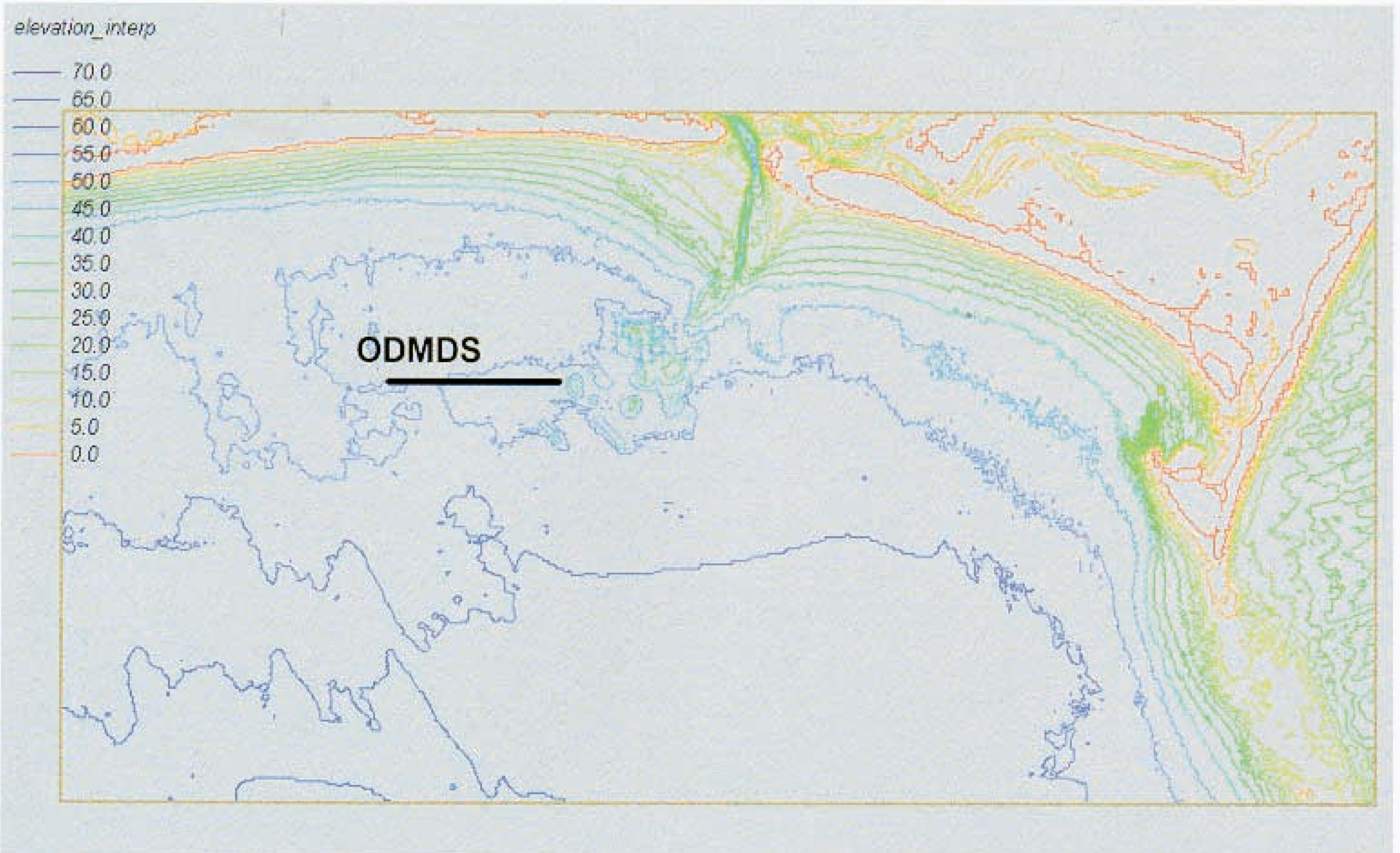


Figure 7.1 Existing Bathymetry

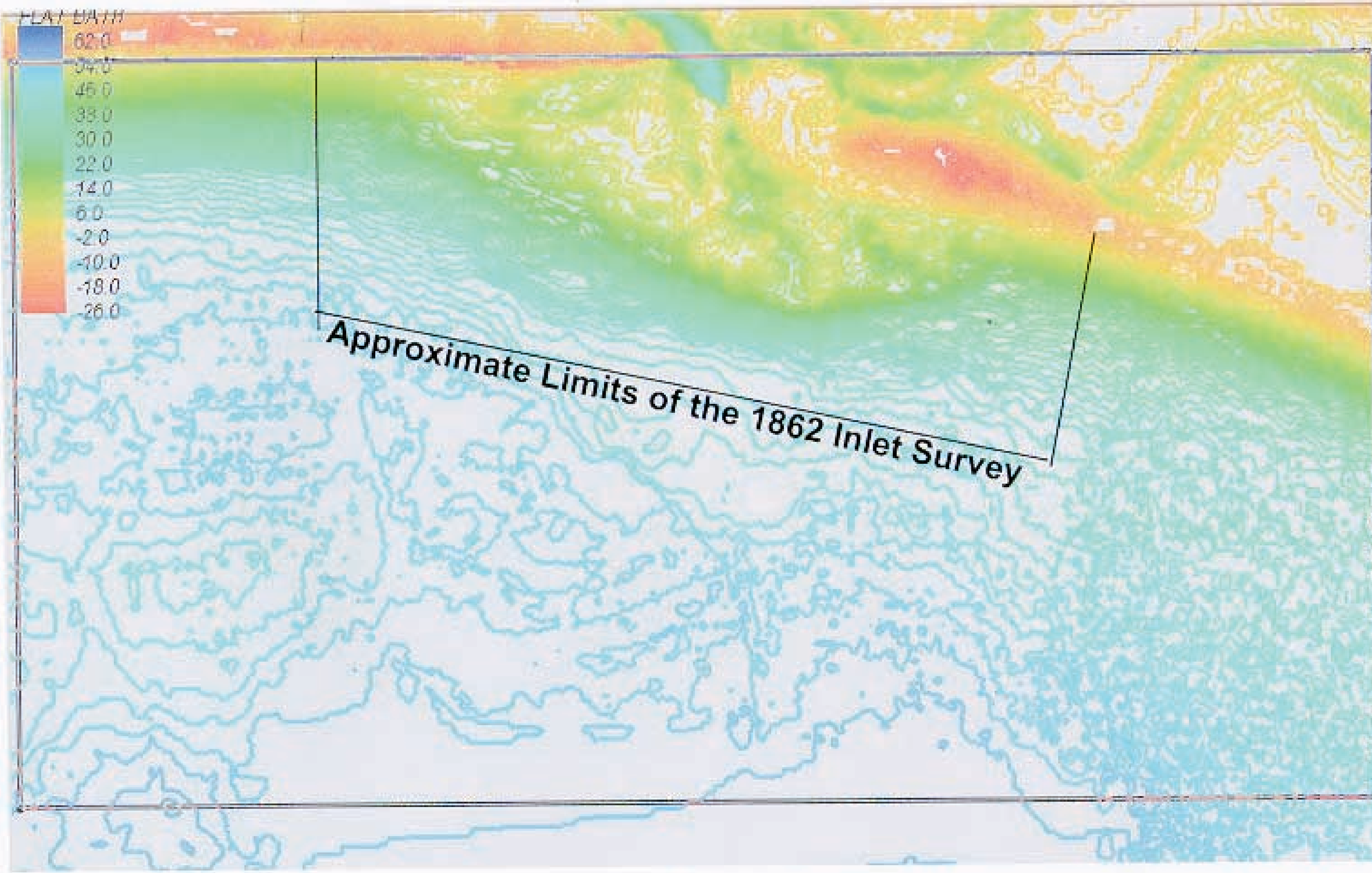


Figure 7.2 1862 Bathymetry (ODMDS removed)

1982 to produce the Phase II wave statistics (WES, 1982) represented a significant improvement over previous wave hindcasting methods, however, differences were noted between the average wave statistics produced by this hindcast procedure and measured wave data obtained by gages located at various points around the coast of the U.S. Based on these observed differences, WES revised its wave hindcasting procedures and recomputed the wave hindcast information in 1995 (WES, 1995). The 1995-hindcast information included tropical storms and hurricanes whereas the previous hindcast information did not. The new 1995 wave statistics computed for two locations off Morehead City Harbor (stations 45 and 46 shown on Figure 7.3) were selected for comparison with the hindcast wave statistics used in the 1990 sediment budget. The 1990 sediment budget analysis used WIS Phase II station 42 from the 1982 wave hindcast. Station 42 for the 1982 hindcast is located in approximately the same location as Station 46 for the 1995 hindcast. The comparison was made for percent occurrence of waves from each 22.5 degree compass direction starting with 0 degrees, which is north, and proceeding clockwise. In addition to the percent occurrence of waves, a comparison was made between the relative wave energy originating from each of these compass directions. The relative amount of the wave energy associated with a particular wave direction was computed by multiplying the frequency of occurrence of a particular wave height and period by the wave height squared times the wave period and then summing all of these products for that direction in accordance with the following equation:

$$(\text{Relative Energy})_{\text{Dir}} = \Sigma((H^2 \text{ x } T) \text{ x } (\text{freq})_{H,T})$$

in which:

H = wave height
T = wave period
$(\text{freq})_{H,T}$ = frequency of occurrence of a particular H and T for a given direction.

The relative energy for each direction was divided by the sum of all of the relative energies for every direction to yield an estimate of the percent energy associated with a particular wave direction.

7.6. The comparison between percent occurrence and percent energy for station 42 of the 1982 hindcast and stations 45 and 46 of the 1995 hindcast is given in Table 7.1. Included in this table are the sums of percent occurrence and percent energy for waves from the four major quadrants; namely, northeast (NE), southeast (SE), southwest (SW), and northwest (NW).

7.7. For the Morehead City Harbor area, waves coming from the southeast quadrant, which ranges from 112.5 degrees clockwise to 180 degrees, would tend to cause sediment transport in a westerly direction whereas waves from the southwest quadrant, which ranges from 202.5 degrees clockwise to 270 degrees, would transport sediment to the east. As can be seen from the percent occurrence and percent wave energy for these various direction in Table 7.1, the 1982 WIS wave information for station 42, which was used in the 1990 sediment budget analysis, indicated a higher percentage of wave occurrence and wave energy coming from the southwestern quadrant which would result in net sediment transport to the east. The 1995 WIS data for stations 45 and 46, on the other hand, indicates just the opposite, with the higher percentage of occurrences and wave energy coming from the southeasterly quadrant. The 1995 WIS wave information would result in sediment transport being predominately to the west.

Table 7.1
Comparison of 1982 and 1995 WIS Phase II Wave Statistics

	1982 WIS Sta. 42		**1995 WIS Sta. 45**			**1995 WIS Sta. 46**		
Wave direction Degrees from N	% Occur. 56-75 hindcast	% Energy 56-75 hindcast	% Occur. 56-75 hindcast	% Occur. 76-95 hindcast	% Energy 76-95 hindcast	% Occur. 56-75 hindcast	% Occur. 76-95 hindcast	% Energy 76-95 hindcast
22.5	5.4	3.0	2.8	2.0	1.66	3.6	2.3	1.23
45	5.5	3.1	4.8	3.7	4.43	3.8	2.0	1.00
67.5	6.0	4.7	4.8	3.0	3.69	2.8	1.4	0.73
90	7.8	6.7	10.0	16.4	13.79	12.5	26.2	31.74
NE Quad	**24.7**	**17.5**	**22.4**	**25.1**	**23.57**	**22.7**	**31.9**	**34.70**
112.5	3.7	2.5	18.9	22.8	18.76	18.5	10.3	15.96
135	2.8	2.0	9.8	15.0	13.50	11.0	15.5	12.25
157.5	3.0	2.5	5.1	6.1	10.34	5.8	6.7	10.53
180	6.7	6.1	8.3	7.7	13.04	10.1	8.8	12.48
SE Quad	**16.2**	**13.1**	**42.1**	**51.6**	**55.64**	**45.4**	**41.3**	**51.22**
202.5	9.5	10.7	6.7	6.1	6.64	8.0	6.1	5.95
225	11.2	14.5	6.9	4.8	5.09	6.3	4.0	3.75
247.5	6.8	10.7	5.4	2.9	2.69	2.7	1.5	0.82
270	5.6	9.9	4.4	2.4	2.28	2.6	1.1	0.34
SW Quad	**33.1**	**45.8**	**23.4**	**16.2**	**16.70**	**19.6**	**12.7**	**10.86**
292.5	5.5	8.5	3.1	1.6	1.08	2.5	1.1	0.53
315	6.7	6.2	3.1	1.8	1.20	2.9	1.5	0.94
337.5	7.1	4.6	2.7	1.7	0.93	3.1	1.6	0.93
0	6.8	4.1	3.3	1.9	0.87	3.7	1.9	0.84
NW Quad	**26.1**	**23.4**	**12.2**	**7.0**	**4.08**	**12.2**	**6.1**	**3.24**

7.8. Thompson, Lin, and Jones (1999) conducted a wave climate and sediment transport potential study for the entrance to the Cape Fear River using the 1995 WIS wave information. Prior to conducting the wave transformation study, they compared the 1995 WIS wave statistics with measured wave data obtained by a National Data Buoy Center buoy and concluded that the WIS information was acceptable, i.e., the directional distribution of wave energy represented by the WIS hindcast wave information agreed well with the measured buoy data. Accordingly, the 1995 WIS wave information was adopted for this study.

7.9. The offshore wave climate used in the analysis was based on the wave statistics provided by the 1995 WIS update for WIS Station 46. Both primary and secondary wave statistics were used, i.e., the wave information includes statistics for waves generated by distance storms as well as locally-generated seas. A comparison of the wave statistics for Station 46 and Station 48, located east of Cape Lookout, indicated comparable concentrations of wave energy approaching from the eastern quadrants, therefore, the wave information for Station 46 was deemed to be representative of waves approaching the area from all offshore directions. Waves approaching the study area from the east (90 degrees) clockwise around to the west (270 degrees) in 22.5-degree increments were transformed from the offshore areas into shallow water. Wave periods used in the analysis ranged from 3.5 seconds to 24.5 seconds in one-second intervals. Wave heights ranged from 1.5 meters to 8.5 meters in one-meter increments.

7.10. STWAVE, a wave transformation model developed by WES (Smith, Resio, and Zundel, 1999), was used for the analysis. STWAVE provides a high degree of wave transformation stability, particularly for wave passing over the complex bathymetry represented by the Cape Lookout Shoals and the shoals associated with Beaufort Inlet, including the ODMDS. However, as noted above, wave breaking and reformation are not completely represented by the model nor is the influence of tidal currents. These limitations result in questionable transformed wave characteristics along the shorelines of Bogue Banks and Shackleford Banks situated immediately adjacent to Beaufort Inlet. In this regard, the transformed waves in these areas have the same degree of uncertainty for the existing bathymetry and the pre-project bathymetry and should provide a reasonable relative indication of the potential impacts that the different ebb tide delta configurations had on sediment transport potential. The boundaries of the grid systems used in the wave transformation analysis, designated as Zone 1, Zone 2, and Zone 3, are shown on Figure 7.4. Zone 1 covers the deep offshore area out to near the edge of the Continental Shelf while Zones 2 and 3 are located in much shallower water. Zone 2 covers the western portion of Bogue Banks west of Longitude 76^{o}-52'-15" and Zone 3 covers the eastern portion of Bogue Banks east of Longitude 76^{o}-52'-15" and all of Shackleford Banks. Longitude 76^{o}-52'-15" is located approximately 0.5 mile west of the west town limit of Pine Knoll Shores and approximately 11 miles west of the Fort Macon terminal groin (west shoulder of Beaufort Inlet). The wave transformation analysis began by propagating waves from Zone 1 toward Zones 2 and 3 and using the transformed waves at the boundaries of the near shore grids to continue the wave transformation into the shallower water depths. Waves approaching the area from the east clockwise around to the south-southeast were stated in Zone 1 east of the Cape Lookout Shoals, i.e., the waves were transformed across Cape Lookout Shoals. Waves from the other directions originated near the offshore boundary of Zone 1.

7.11. URS Corporation determined the potential sediment transport rate at 200-foot intervals along the Bogue Banks and Shackleford Banks shorelines in the following manner:

(a) STWAVE was used to transform each incident wave condition to the point of near breaking;

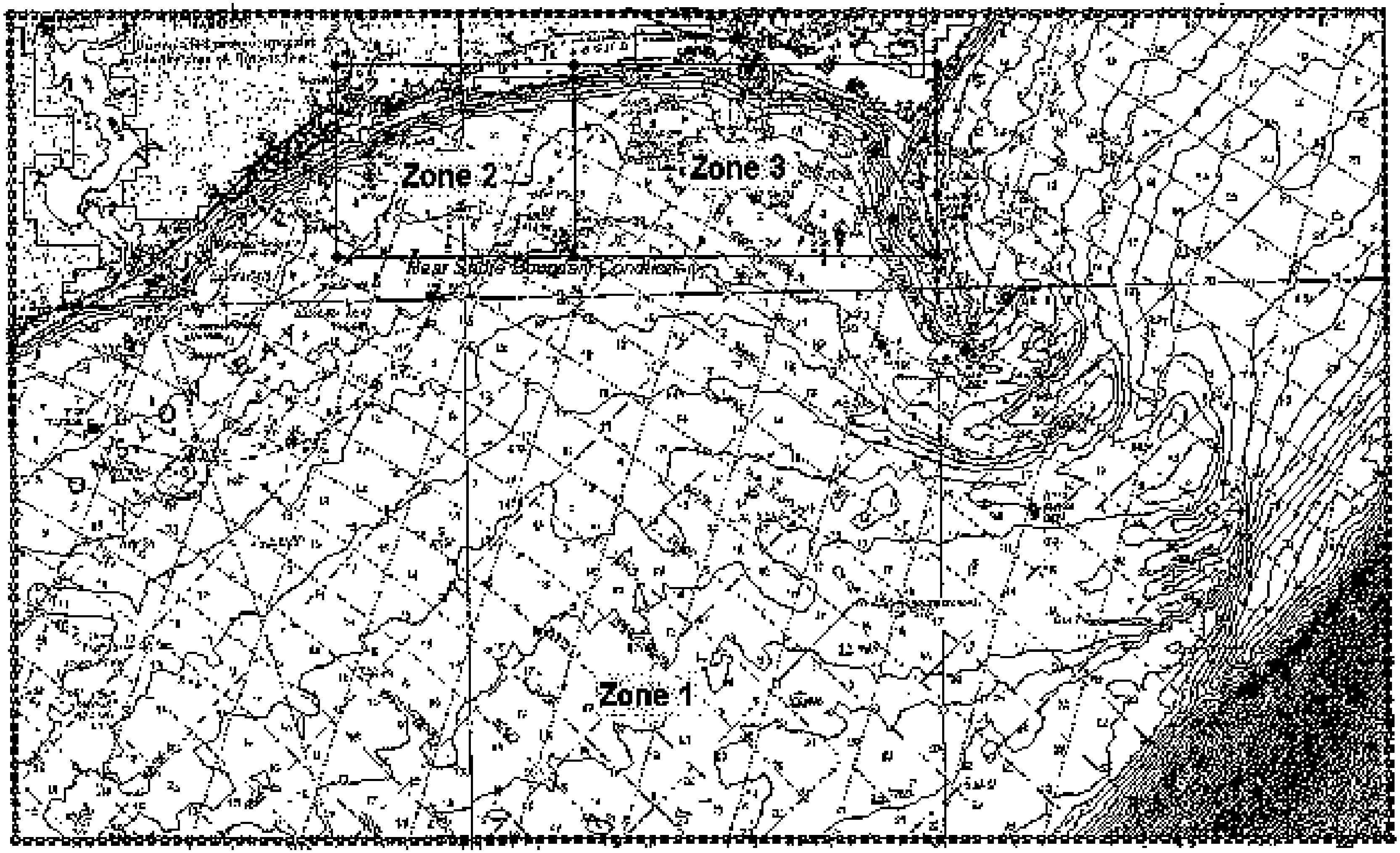
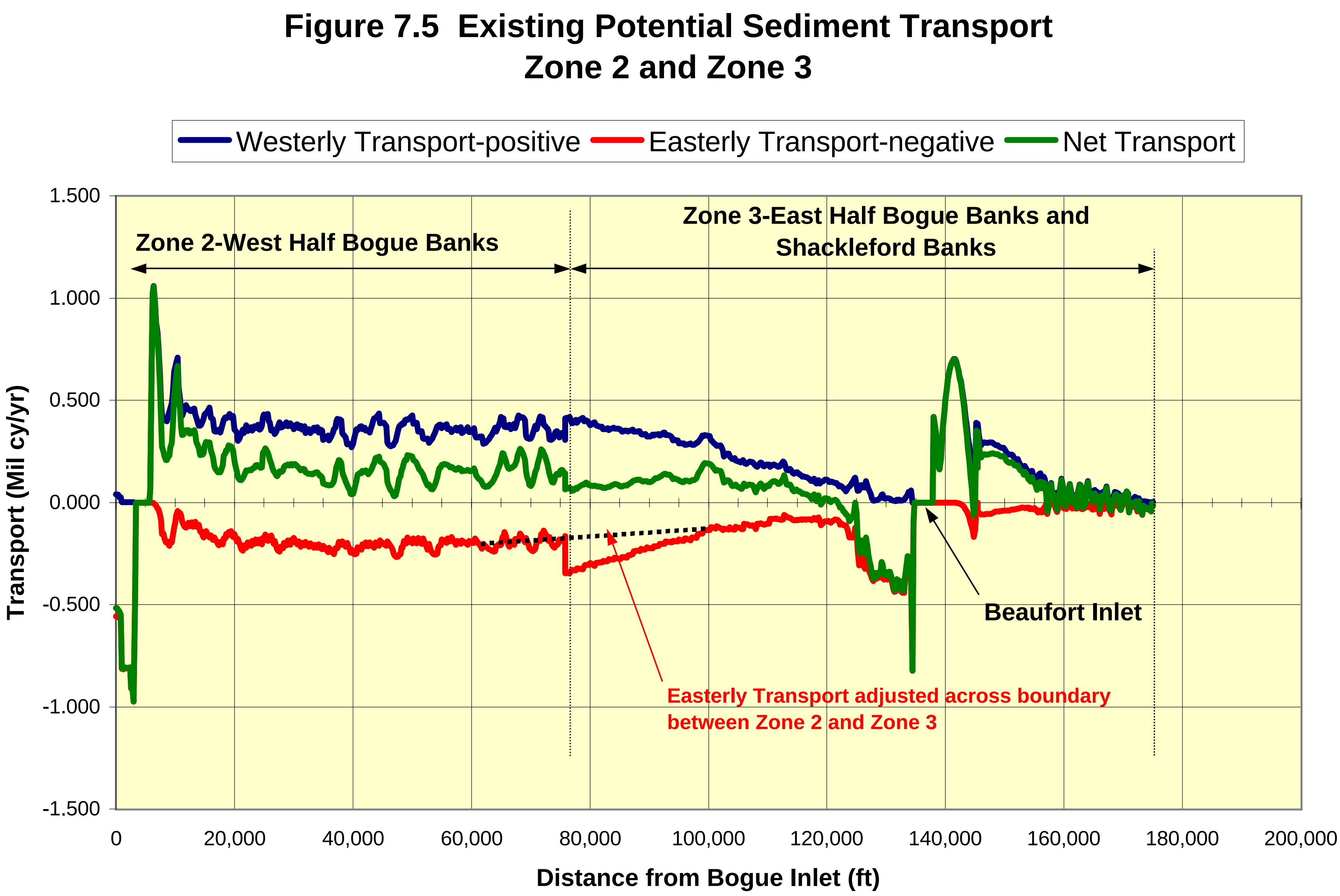


Figure 7.4 Grid System Used in the Wave Transformation Analysis

(b) Each wave condition was weighed in proportion to its occurrence in the wave hindcast record;
(c) The near-breaking wave was transformed to the point where breaking begins;
(d) The potential longshore sediment transport rate was determined for each incident wave condition based on the breaking height of the wave and the shoreline approach angle;
(e) The weighted sediment transport potentials at each 200-foot point along the shorelines were summed to determine estimates of the annual westward, eastward, and net longshore transport rates.

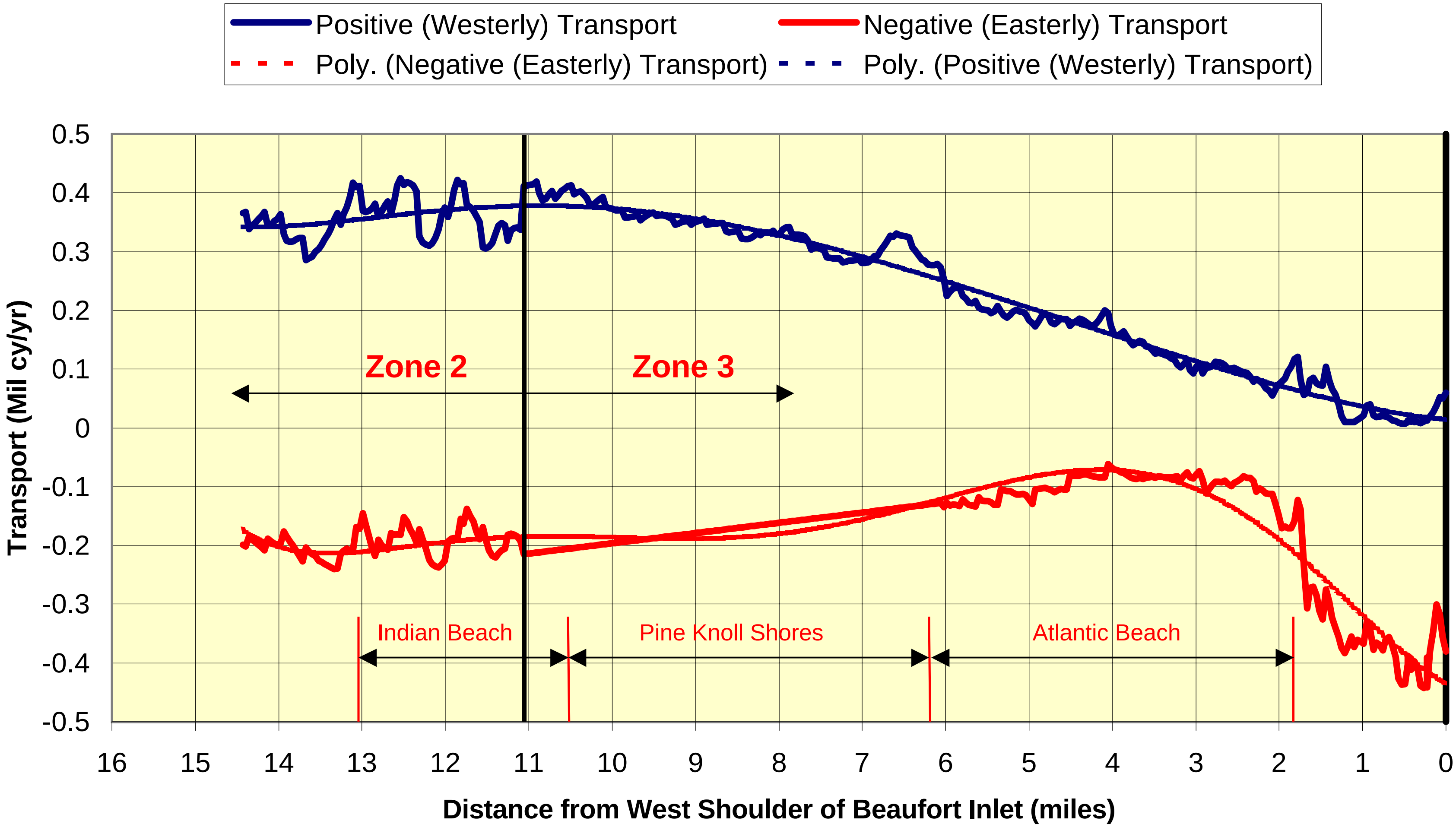
Breaking wave conditions were determined by applying a technique described in the Coastal Engineering Manual (Corps of Engineers, 1988), which is based on transforming deepwater waves to breaking wave conditions using linear wave theory.

7.12. Results of the Potential Sediment Transport Analysis. The potential sediment transport rates for the existing condition are shown on Figure 7.5 for Zone 2 and Zone 3 combined. The data is plotted relative to its distance from Bogue Inlet, located at the west end of Bogue Banks. As noted on Figure 7.5, some adjustments had to be made in the transport potential computed near the boundary of Zones 2 and 3. In this particular region, boundary conditions between the two near shore zones affected the numerical results. The adjustment was made by projecting the stable results from Zone 2 west of the boundary to stable points in Zone 3 east of the boundary. These adjusted sediment transport rate potentials for a portion of Zone 2 that includes Indian Beach and Zone 3 on Bogue Banks, are shown Figure 7.6. The reference point for the data plotted on Figure 7.6 is the west shoulder of Beaufort Inlet with the distance given in miles from the inlet. Potential sediment transport rates on the east end of Bogue Banks, between the east town limit of Atlantic Beach and Beaufort Inlet (the Fort Macon State Park shoreline), have a high degree of variability which is the result of the complex and variable wave transformation that occurs as waves propagate across the ebb tide delta of Beaufort Inlet and the ODMDS. The results obtained for the 1862 condition in Zone 3 are presented on Figure 7.7. As noted on this figure, adjustments in the computed potential sediment transport rates were also made across the boundary between Zone 2 and Zone 3. The adjustments made in the 1862 rates were similar to the adjustments made for the existing condition. The adjusted pre-project potential sediment transport rates for Zone 2 and Zone 3 on Bogue Banks are shown on Figure 7.8 relative to their distance from Beaufort Inlet. As was the case for the existing bathymetry, the sediment transport potentials along the Fort Macon State Park shoreline are highly variable, which in this case, the variable results are due to the configuration of the Beaufort Inlet ebb tide delta as the 1862 bathymetry did not include the ODMDS. Potential sediment transport rates on Shackleford Banks for the existing and 1862 conditions are shown on Figures 7.9 and 7.10 respectively. The sediment transport potentials determined for the extreme west end of Shackleford Banks did not have the same degree of variability as the extreme east end of Bogue Banks, however, sediment transport potentials along the remainder of the island, particularly sediment transport potentials to the west, were highly variable for both the 1862 and existing bathymetry. This variability is primarily due to the transformation of waves from the east and southeast directions over the Cape Lookout Shoals.



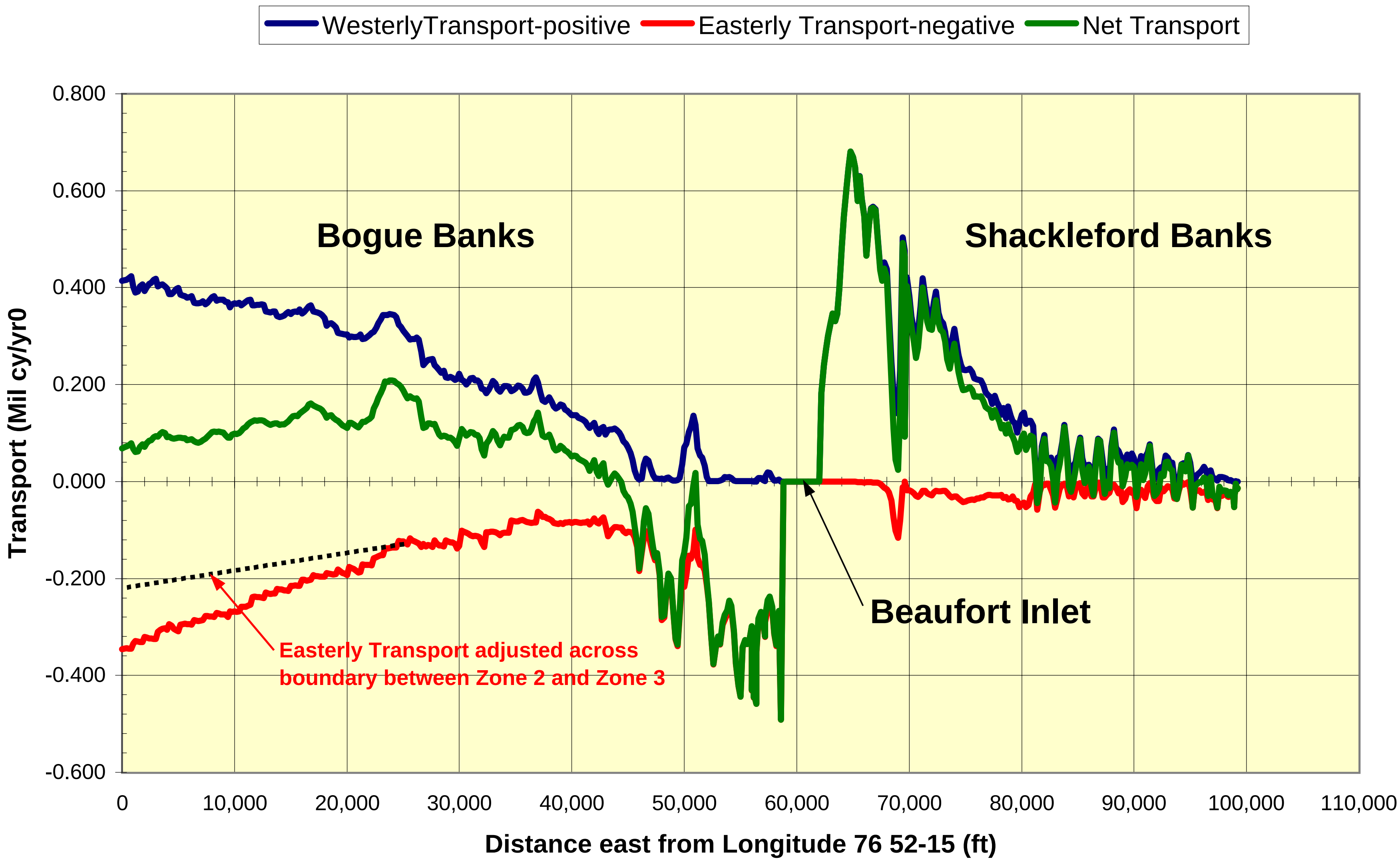
potential transport URS
fig 7.5

Figure 7.6 Sediment Transport Potential
Zone 2 and Zone 3 Bogue Banks
Existing Bathymetry



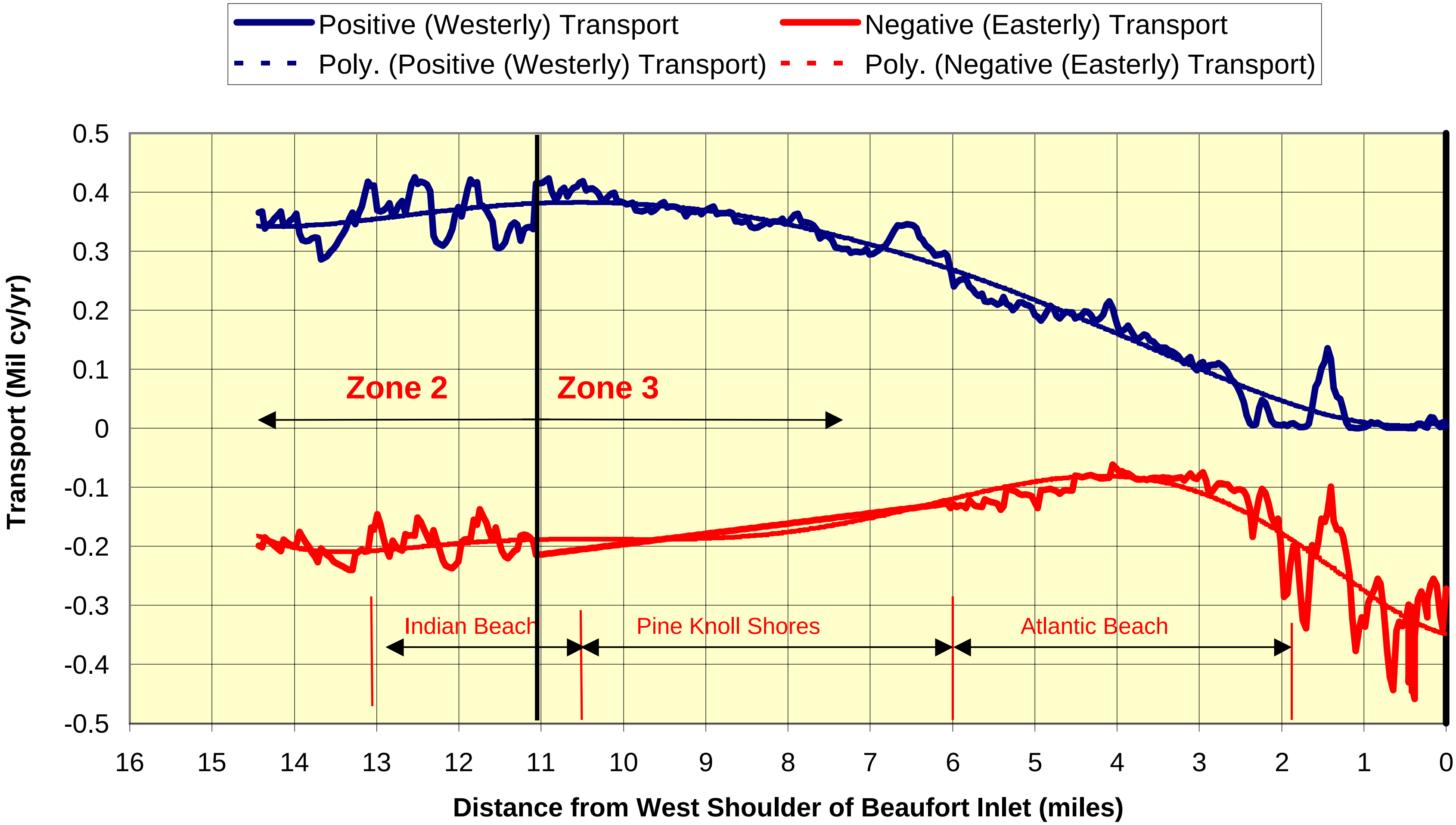
1862 Current Transport.xls
fig 7.6

Figure 7.7 1862 Potential Sediment Transport Zone 3



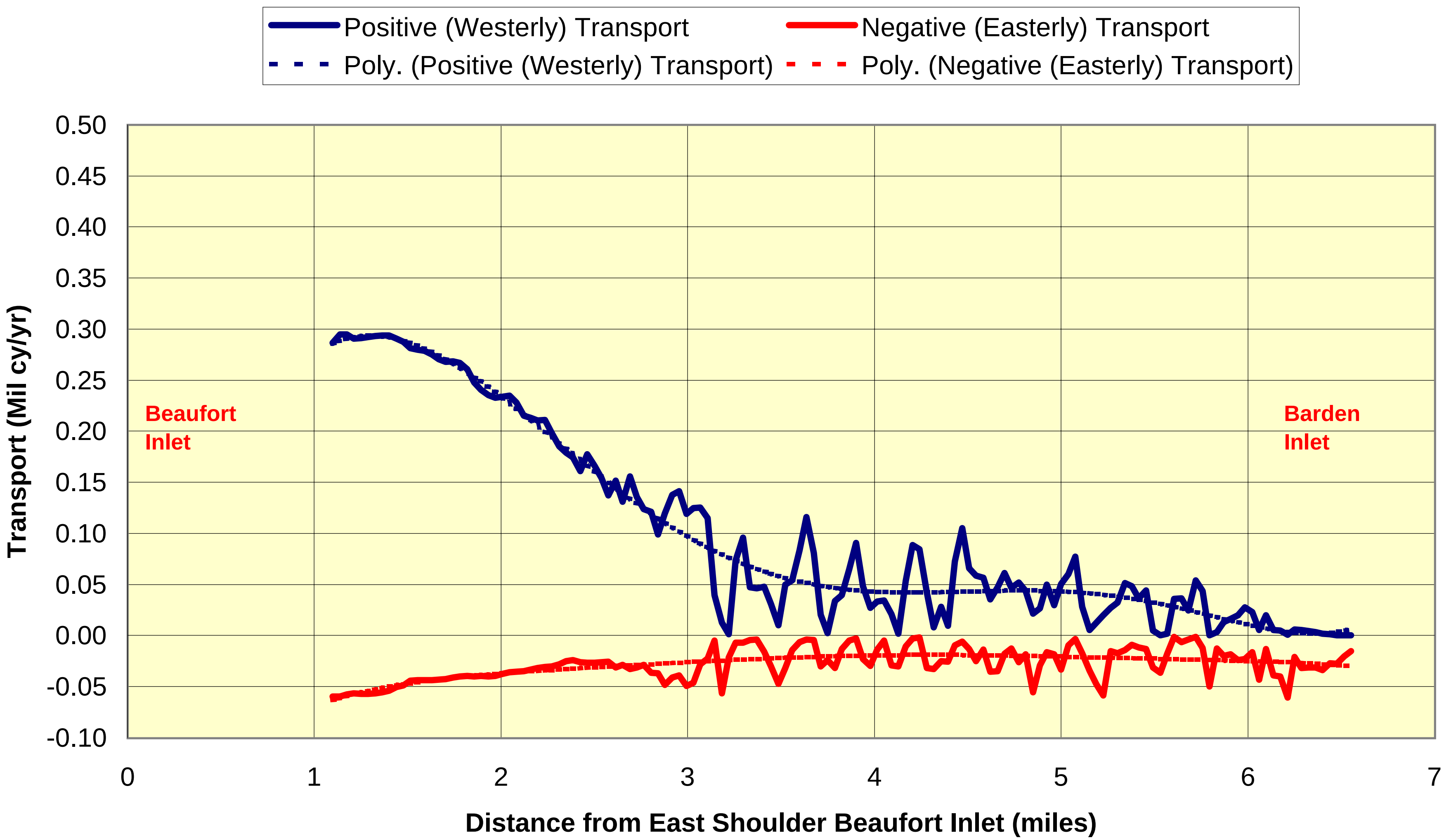
potential transport URS
plot 1862 trans

Figure 7.8 Sediment Transport Potential
Zone 2 and Zone 3 Bogue Banks
1862 Bathymetry



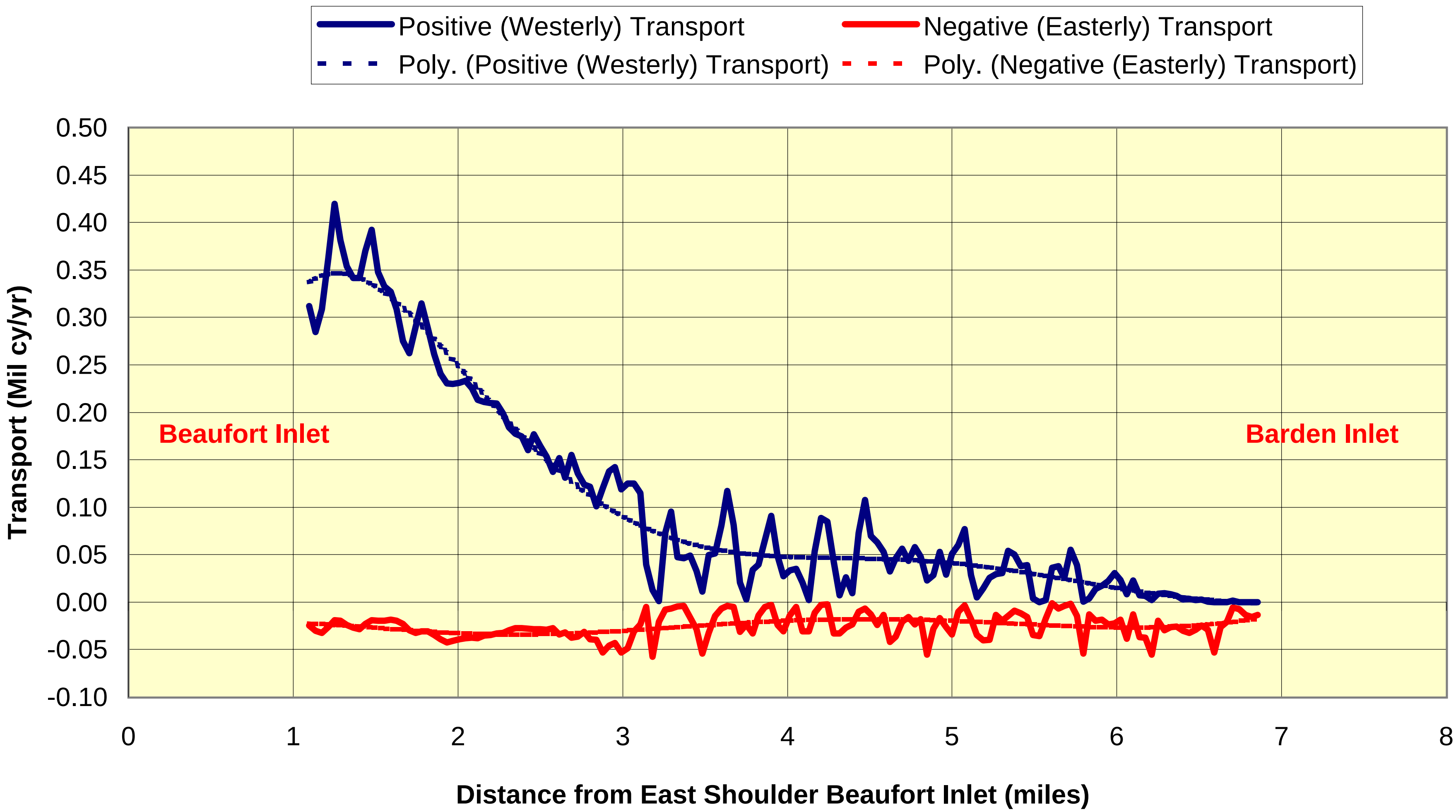
1862 Current Transport.xls
fig 7.8

Figure 7.9 Sediment Transport Potential-Zone 3 Shackleford Banks Existing Bathymetry



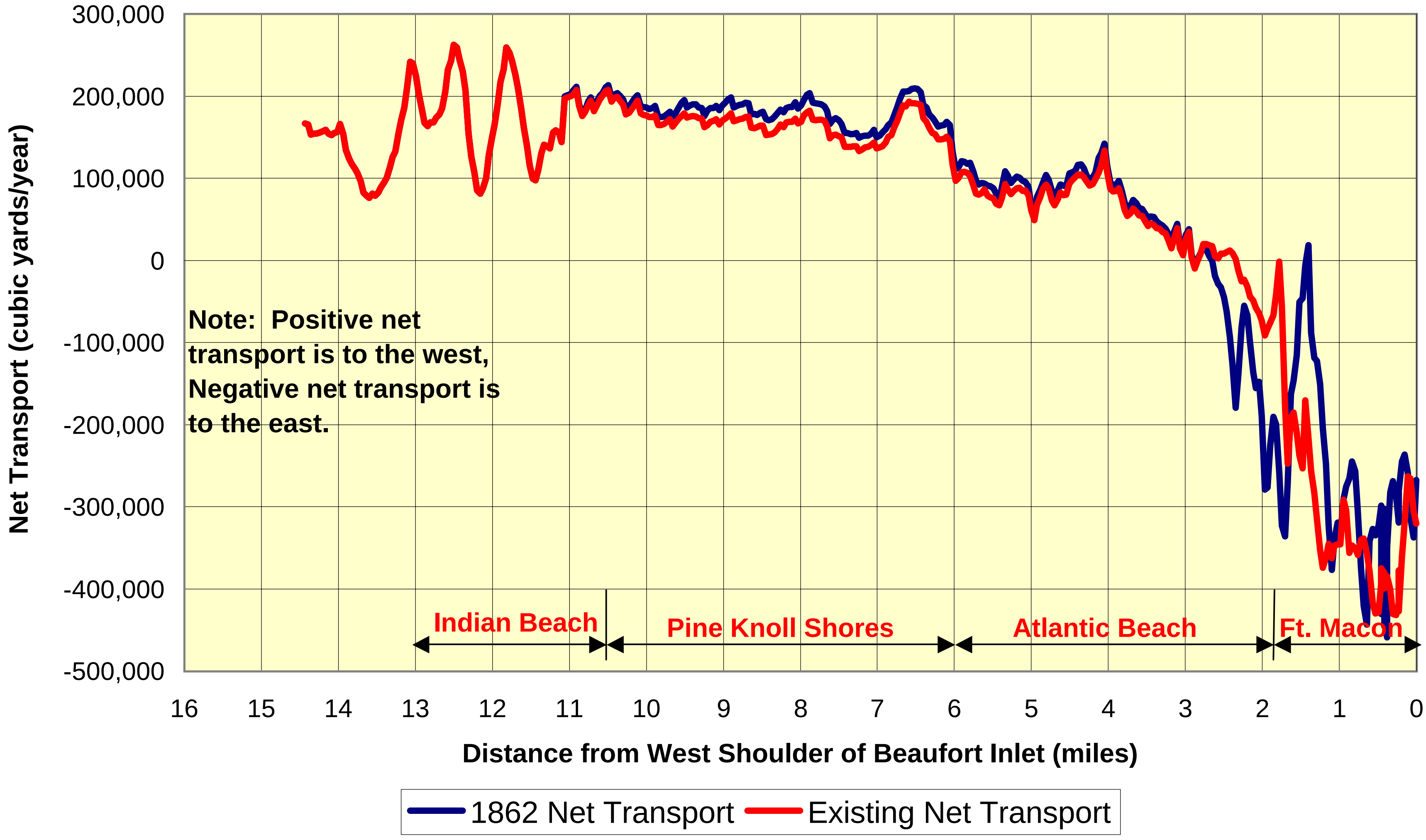
1862 and Current Transport
Current Shack plot

Figure 7.10 Sediment Transport Potential-Zone 3 Shackleford Banks
1862 Bathymetry



1862 Current Transport.xls
1862 Shack plot

Figure 7.11 Bogue Banks Net Transport Rates for the 1862 Bathymetry and Existing Bathymetry



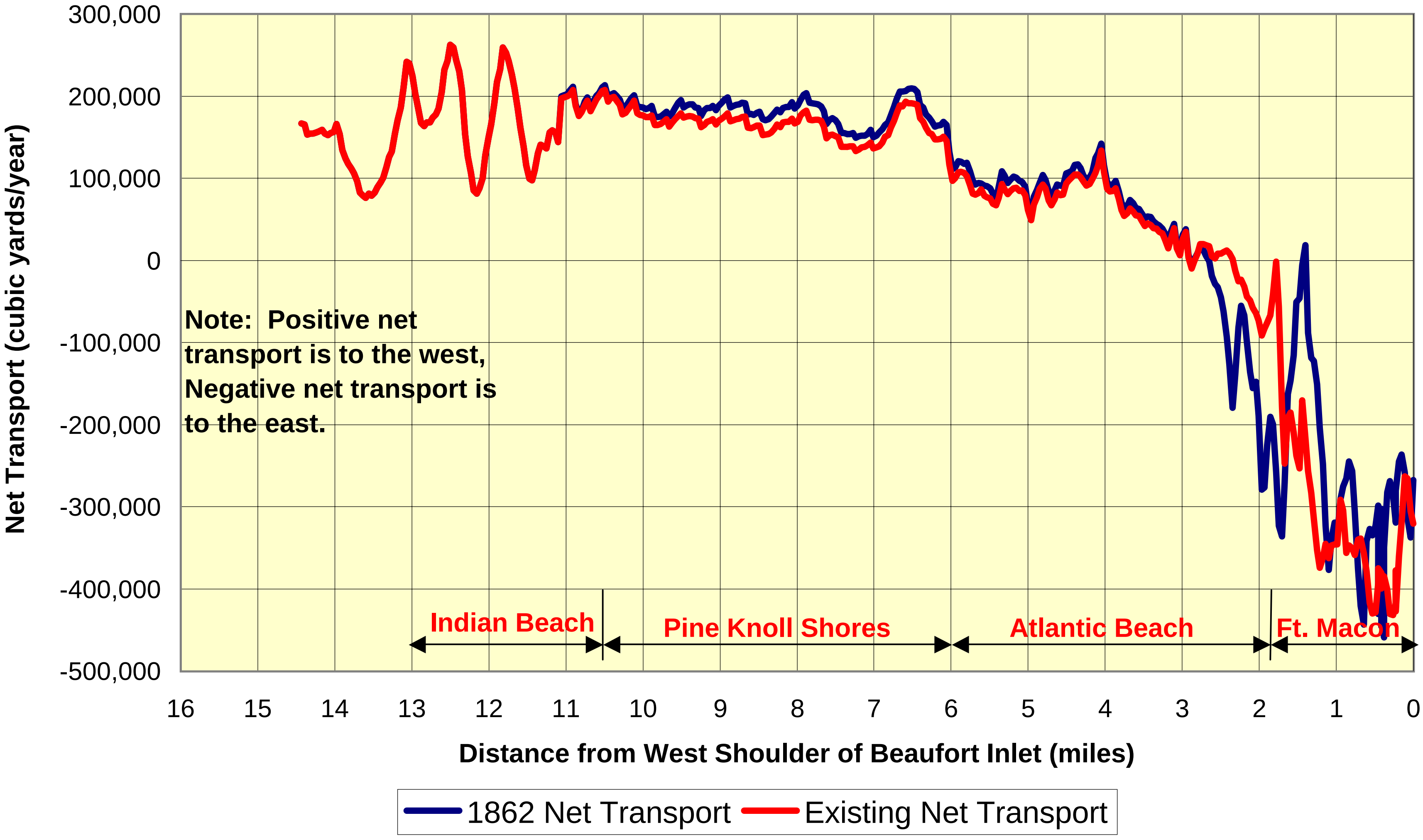
1862 Current Transport.xls
7.11 Bogue Net trans rates

7.13. Difference in Longshore Sediment Transport Potential for Pre-Project and With-Project Cases. The only difference in the input data for the pre-project and with-project sediment transport analyses was the offshore bathymetry. As discussed above, the pre-project bathymetry simulated the 1862 inlet condition and excluded the large offshore mounds created by offshore disposal of the inlet channel dredged material. Accordingly, differences computed for the potential sediment transport on both Bogue Banks and Shackleford Banks were due entirely to the differences in offshore bathymetry. In the discussions that follow, the numerical results associated with the potential sediment transport analyses for the pre-project and existing conditions should not be regarded as representing absolute values. Rather, the results are only indicative of the potential changes in potential sediment transport direction and magnitude associated with the changes in offshore bathymetry attributable to the construction, operation, and maintenance of the Morehead City Harbor project.

7.14. Bogue Banks Differences. The analysis for both the pre- and with-project conditions indicated that the predominant direction of net littoral transport on Bogue Banks near Beaufort Inlet is to the east while sediment transport is predominantly to the west over the remainder of Bogue Banks. This is illustrated in Figure 7.11, which shows the net rate of transport along the east half of Bogue Banks for both the 1862 and existing bathymetry. The net rate of transport is the difference between the sediment transport potential to the west and east at each point along the shoreline. Positive net transport rates indicate predominant sediment transport to the west. For the pre-project condition, the point where sediment transport switches from predominantly east to predominantly west, commonly referred to as a "nodal point", was located approximately 2.6 miles from the west shoulder of Beaufort Inlet. For the with-project condition, the nodal point was located about 2.3 miles from the inlet or 0.3 miles closer to the inlet. The eastward movement of the nodal point was directly due to the reconfiguration of the Beaufort Inlet ebb tide delta from its bulbous shape in 1862 to its present deltaic shape. The present shape of the delta causes waves from the southeastern quadrant to undergo a greater degree of refraction than that associated with the 1862 bathymetry. Under existing conditions, sediment transport to the east increases rather dramatically near the west boundary of the Fort Macon State Park, whereas the increase in easterly transport was more gradual in this area for the pre-project case. Sediment transport to the east along the Fort Macon shoreline was generally greater under existing conditions than for the pre-project case. This indicates that waves now have the potential to transport greater volumes of littoral sediment into Beaufort Inlet compared to the pre-project case.

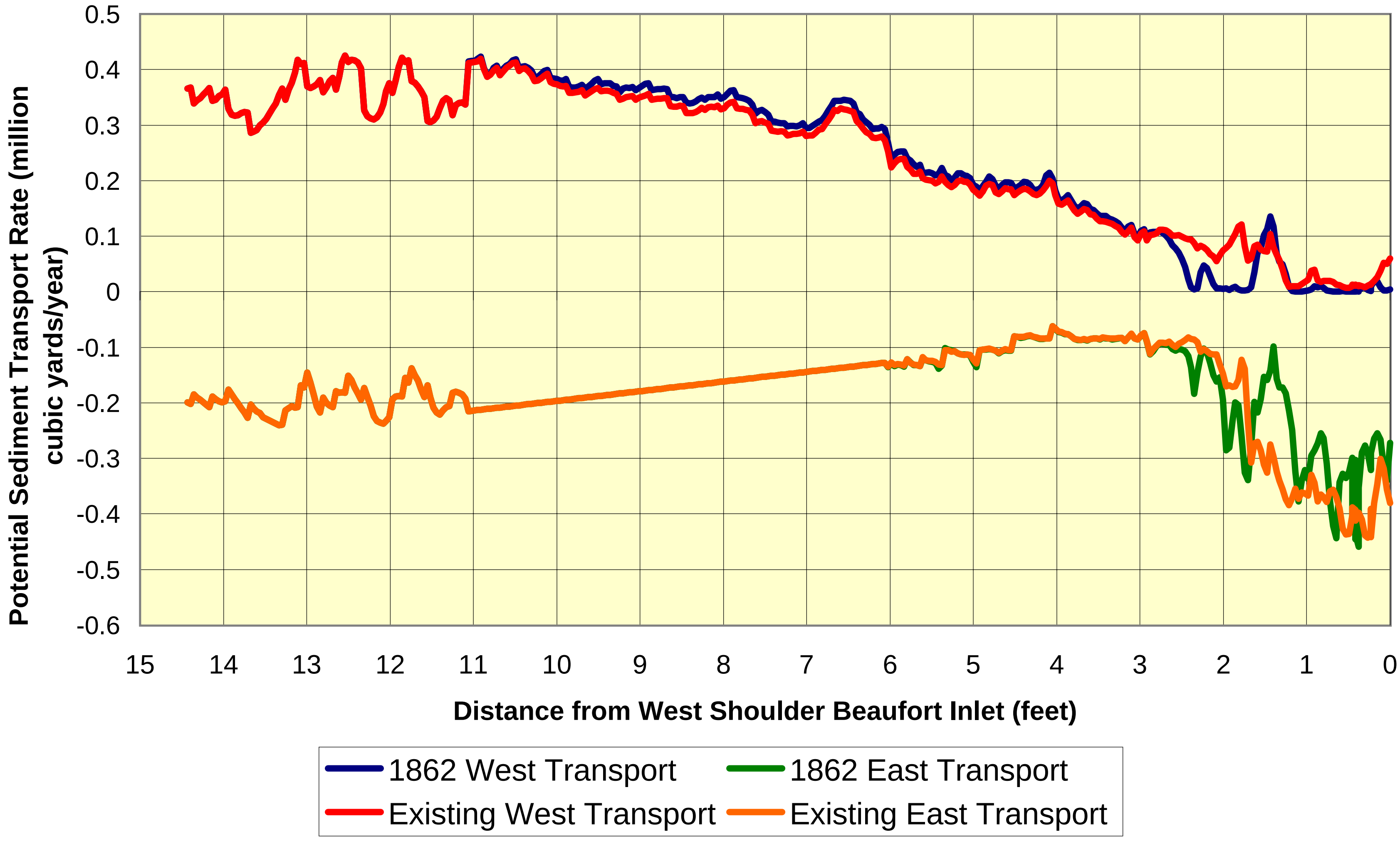
7.15. Potential sediment transport rates along Bogue Banks determined for the 1862 and existing bathymetric conditions are shown superimposed on Figure 7.12. Significant differences in sediment transport potential for the two conditions occurred in the area approximately 2.8 miles west of Beaufort Inlet. For both cases, sediment transport potential to the west in this zone was relatively small but with the sediment transport potential associated with the existing condition being slightly greater. Sediment transport potential to the east increased rather dramatically at a point approximately 1.8 miles from Beaufort Inlet for the existing condition resulting in a greater net transport to the east compared to the 1862 condition. As stated previously, within the area east of the nodal

Figure 7.11 Bogue Banks Net Transport Rates for the 1862 Bathymetry and Existing Bathymetry



1862 Current Transport.xls
7.11 Bogue Net trans rates

Figure 7.12 Potential Sediment Transport Rates-Bogue Banks
1862 and Existing Bathymetry



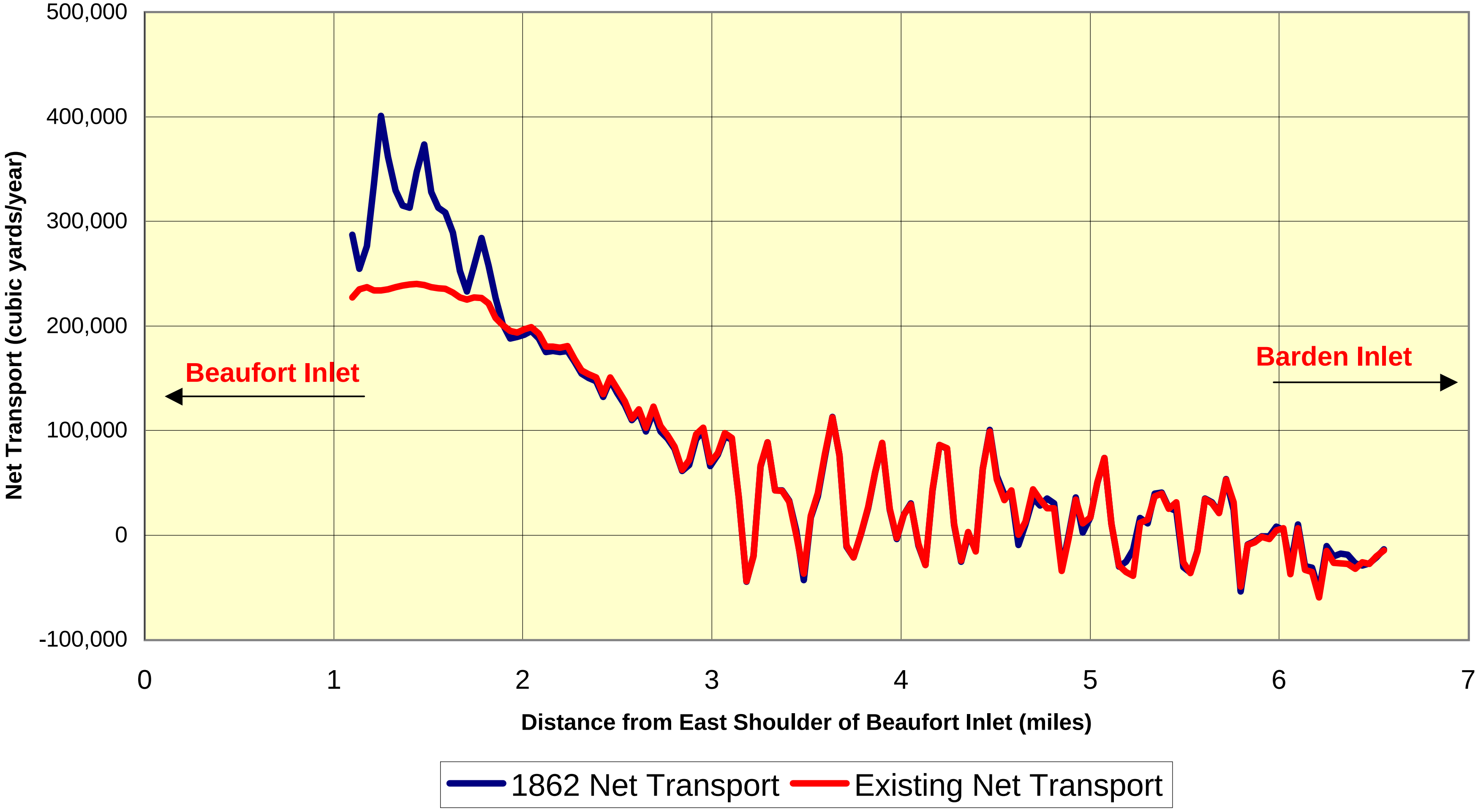
1862 and Existing Transport.xls
Bogue 1862 and Existing Trans

point, net sediment transport potential to the east or toward Beaufort Inlet for the existing condition is significantly greater than the transport potential computed for the 1862 condition. For the remainder of Bogue Banks west of mile 2.8, sediment transport potential to the east was essentially identical for both conditions with only minor differences determined for the sediment transport potential to the west. The relatively small differences in west transport was due to the impacts of the ODMDS on wave transformation as changes in the shape of the Beaufort Inlet ebb tide delta did not affect wave conditions outside the area 2.8 miles from the inlet. The relatively small differences in potential sediment transport along Bogue Banks west of mile 2.8 indicates that changes in the offshore bathymetry associated with the Morehead City Harbor project have not significantly affected sediment transport along most of Bogue Banks, particularly in the vicinity of Pine Knoll Shores, and therefore is not a factor with regard to impacts of the harbor project on the shoreline of Bogue Banks. The higher rate of potential sediment transport to the east within the area 2.8 miles from Beaufort Inlet could possibly have a negative impact in this area, but as discussed later, the 3 beach disposal operations that have placed material on the east end of Bogue Banks since 1978 have effectively compensated for this potential impact.

7.16. Shackleford Banks Differences. The net rate of potential sediment transport along Shackleford Banks relative to the distance from Beaufort Inlet for the 1862 pre-project bathymetry and the existing bathymetry is plotted on Figure 7.13. A comparative plot of the potential sediment transport to the east and west for both the 1862 and existing condition is shown on Figure 7.14. As was the case for Bogue Banks, the only significant difference is sediment transport potential along Shackleford Banks was in a region two miles east of Beaufort Inlet. Outside or east of this region, there was virtually no difference in sediment transport potential. Within the area two miles east of the inlet, the potential for sediment transport to the west or into Beaufort Inlet was considerably less for the existing condition compared to the 1862 condition. This major change in sediment transport off of Shackleford Banks indicates that sediment losses off Shackleford Banks to Beaufort Inlet should be less under existing conditions, i.e., the impacts on Shackleford Banks shoreline should be positive.

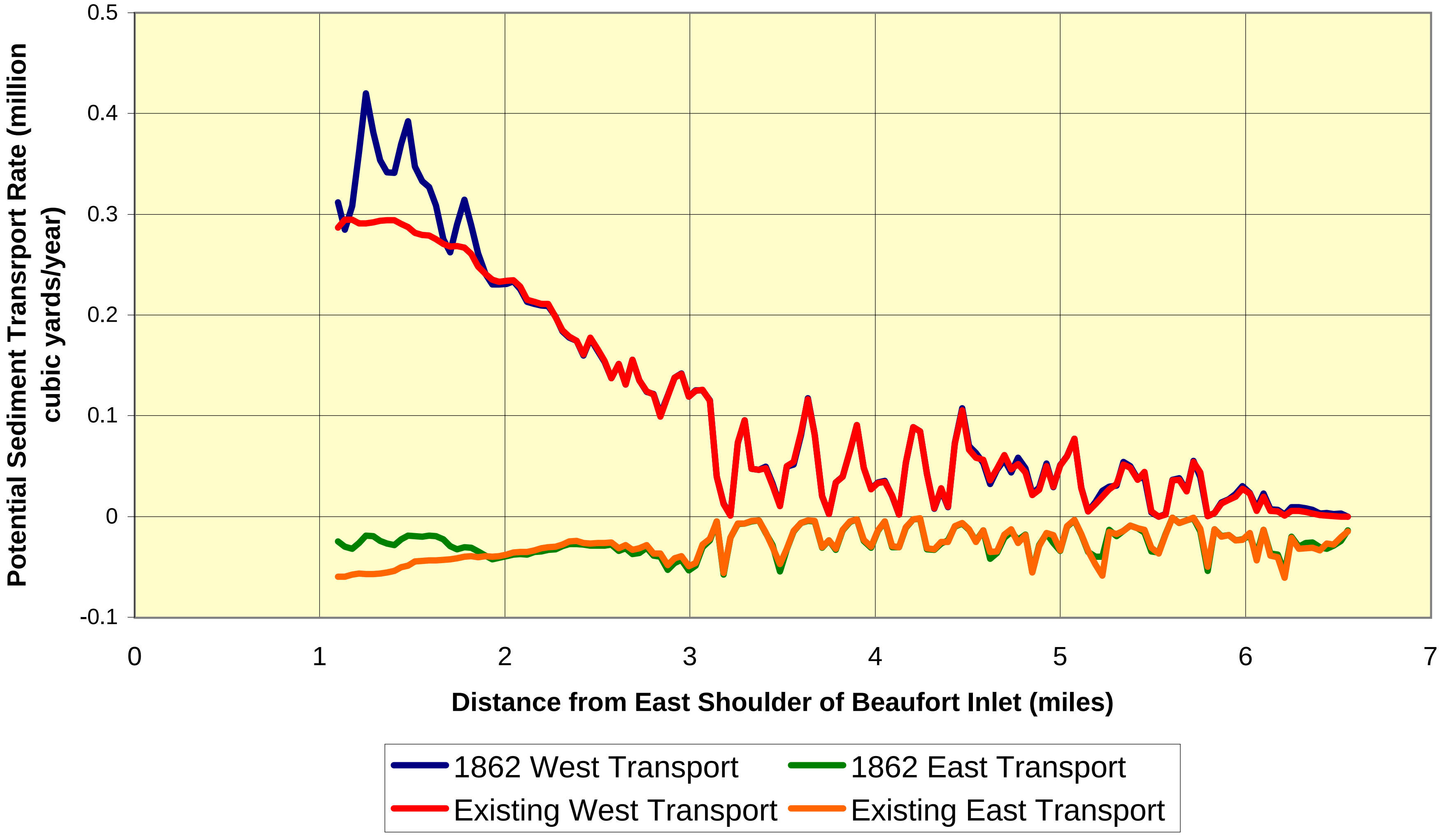
7.17. Changes in the potential rate of sediment transport on the west end of Shackleford Banks are directly attributable to the physical changes in the configuration of the ebb tide delta of Beaufort Inlet. The 1862 inlet bathymetry had the ocean bar channel oriented in a southeasterly direction and a relatively small seaward protrusion of the ebb tide delta relative to the existing ebb tide delta (see Figures 7.1 and 7.2). This resulted in the offshore depth contours along Shackleford Banks closely paralleling the 1862 shoreline to a point very near the inlet. This condition would have allowed the waves propagating from the southeast quadrant to expend their energy relatively close to the inlet. For the existing condition, the seaward protrusion of the Beaufort Inlet ebb tide delta that has developed with the construction and maintenance of the Morehead City Harbor project has caused the depth contours seaward of Shackleford Banks to swing seaward near the inlet (see Figure 7.1). In addition, the shoreline on the west end of Shackleford Banks has developed a slight bulge near the area where the ebb tide delta depth contours merge with the shore parallel contours off Shackleford Banks. The reorientation of the offshore

Figure 7.13 Shackleford Banks Net Transport Rates for the1862 and Existing Bathymetry



1862 Current Transport.xls
Shack net transport

Figure 7.14 Potential Sediment Transport Shackleford Banks 1862 and Existing Bathymetry



1862 and Current Transport.xls
Shack 1862 and Existing Trans

depth contours near Beaufort Inlet combined with the shoreline bulge results in waves breaking at a smaller angle relative to the shoreline, thus producing a lesser amount of longshore wave energy and potential sediment transport.

7.18. Summary of Wave Transformation/Sediment Transport Analysis. The major difference in sediment transport potential along both Bogue Banks and Shackleford Banks for the pre-project and with-project conditions occurred in areas located within 2.8 miles west of Beaufort Inlet and 2 miles east of Beaufort Inlet respectively. West and east of these points, the indicated changes were relatively minor. On Bogue Banks, the differences in the potential longshore sediment transport rates between the pre-project and with-project conditions would indicate that the physical changes in the offshore bathymetry associated with the Morehead City Harbor project could potentially impact the shoreline east of the 2.8 mile point, however, this potential impact has been eliminated by the disposal of dredged material from the harbor project on the east end of Bogue Banks. On Shackleford Banks, changes in sediment transport potential between the pre-project and with-project conditions within the area 2 miles east of Beaufort Inlet indicate that sediment losses off of the island under existing conditions should be less than the losses associated with the 1862 condition. The majority of the island from a point 2 miles east of Beaufort Inlet to Barden Inlet experienced little to no change in sediment transport potential as a result of the bathymetric changes associated with the Morehead City Harbor project. Based on these results, changes in wave transformation and sediment transport potential associated with the bathymetric changes caused by the Morehead City Harbor project have not significantly impacted the Bogue Banks shoreline west of the 2.8 mile point from Beaufort Inlet and the Shackleford Banks shoreline east of the 2.0 mile point.

7.19. Shoreline Changes-Introduction. Section 111 specifically addresses shoreline damages attributable to the operation and maintenance of Federal navigation projects and provides authority for the Corps to investigate, study, plan and implement structural and nonstructural measures to prevent or mitigate such damages. The degree of mitigation is limited to restoration of the affected shoreline to a level that would have existed in the absence of the navigation project at the time the project was accepted as a Federal responsibility. Accordingly, the determination of possible project related shoreline impacts relies on the comparison of shoreline changes occurring prior to the project with shoreline changes occurring with the project. If the construction, operation, and maintenance of the project has had or is having an impact on the adjacent shorelines, the impact should be present in the shoreline change history.

7.20. Construction and maintenance of the Morehead City Harbor project actually began in 1911, but as explained previously, major improvements were not initiated until 1936 when the project was deepened to 30-feet mlw. Therefore, for purposes of this study, the time prior to 1936 is assumed to represent the pre-project period.

7.21. The Morehead City Harbor project has been modified several times since 1936. In 1961, the project was deepened to 35 feet mlw. In 1978, the ocean entrance channel through Beaufort Inlet was deepened to 42 feet mlw and the interior channels and basins deepened to 40 feet mlw. In addition, the 1978 modification designated Brandt Island as a temporary holding area for dredged material removed from the inner harbor. Every 8 to 10 years, the material stored in Brandt Island is removed and deposited in a beach disposal area located on the east end of Bogue Banks. The designated beach disposal area extends from Beaufort Inlet 7 miles down Bogue Banks and includes the entire ocean shoreline fronting the Fort Macon State Park, Town of Atlantic Beach, and approximately 1.3 miles of the shoreline fronting the Town of Pine Knoll Shores. The most recent modification of the project was accomplished in 1994 with the deepening of the ocean entrance channel to 47 feet mlw and the deepening of the interior channels and basins to 45 feet mlw. This latest modification also included provisions for a near shore or shallow water disposal site for material removed from the ocean entrance channel. The near shore disposal site is presently located west of the entrance channel as shown on Figure 2.3. Since 1997, slightly less than one-half of the ocean entrance channel maintenance material has been deposited in this near shore site with the balance of the material placed in the ODMDS. Due to the incremental nature of all of the improvements and modification to the project, the time period beginning in 1978 and extending to the present was designated as the with-project period. Since 1978, maintenance dredging in the ocean entrance channel has averaged 644,000 cubic yards/year with an additional 200,000 cubic yards/year removed to maintain the inner harbor. Also, dredged material from the construction and maintenance of the harbor project was deposited on the east end of Bogue Banks on three separate occasions. In this regard, the disposal of dredged material on the east end of Bogue Banks is an integral feature of the Morehead City Harbor project and the impacts of this feature are included in the overall assessment of the project impacts on the adjacent shorelines.

7.22. Data Sources and Error Estimates. The pre-project shoreline histories on Bogue Banks and Shackleford Banks were determined from the comparison of historic maps prepared by the National Ocean Service (NOS) formerly known as the U.S. Coast and Geodetic Survey and the U.S. Coast Survey. All maps had a scale of 1:20,000. The shorelines shown on the historic maps dated in the 1800's represent the mean high water shorelines, which were generally determined in the field by standard rod surveys or planet table surveys. The field accuracy for the location of the mean high water line is of the order of plus or minus (+/-) 20 feet. Determining the location of the mean high water line from these maps introduces additional errors due to the width of the line representing the high water line, the location of reference points, and measurement errors. In all, the location of the shoreline from a particular map is considered to have a total error of +/- 50 feet. The 1800 shorelines for Bogue Banks and Shackleford Banks were compared to shorelines shown on maps dated 1933 and 1946 respectively. The 1933 and 1946 maps were prepared from aerial photographs with the accuracy of the shoreline location within +/- 35 feet. Again, determining the location of the mean high water line relative to a reference line would introduce additional errors resulting in a total accuracy of +/- 55 feet. Since measurement errors are random in nature, the comparison of a shoreline positions from one map with that on another does not necessarily result in a compounding of the measurement error, i.e., measurement errors from one map may cancel the measurement errors from another map. For purposes of this study, the comparison of historic mean high water shorelines from the historic maps was assumed to be within +/-

50 to +/- 55 feet for each measurement point or station with the overall error for average shoreline changes over relatively long shoreline segments being +/- 25 feet. The time period used in the pre-project shoreline change analysis ranged from 56 to 92 years. Therefore, the average annual shoreline change rate determined over relatively long shoreline segments should be accurate to within +/- 0.5 foot/year. The with-project shoreline histories on Bogue Banks and Shackleford Banks were determined from beach profile surveys conducted by the Corps of Engineers. The beach profile surveys determine the cross-section of the beach by measuring the ground elevation at intervals equal to or less than 25 feet. The location of the +6-foot msl and 0-foot msl contour positions relative to the Corps of Engineers baseline were interpreted from these surveys and the average position of these two contours designated as the shoreline position. By using the average position of the +6-foot msl and 0-foot msl contours, any change in beach slope from one survey to another would be taken into account. The accuracy of the shoreline changes determined from the profile data is considered to be +/- 10 feet. Since the 1978 and 2001 surveys did not use the same profile stations, additional errors were introduced by interpolating the position of the shorelines from these two surveys and the rate of change in shoreline positions to common points along Bogue Banks. This is discussed further below.

7.23. In addition to the 1978 and 2001 beach profile surveys that covered the entire length of Bogue Banks, offshore profile surveys have been conducted on the eastern 6 miles of Bogue Banks since 1958 and along the entire length of Shackleford Banks since 1980. These offshore profile surveys were evaluated to determine if the Morehead City Harbor project is having any significant impact on the offshore profiles of these two beaches. Since the only offshore survey covering all of Bogue Banks was only made once (April 2001), comparative analysis of offshore changes were not possible for the entire island. The discussion of the offshore changes follows the sections on pre-project and with-project shoreline changes.

7.24. Pre-Project Shoreline Changes on Bogue Banks. The earliest pre-project shoreline position for Bogue Banks was obtained from an 1854 survey, which covered the eastern 5 miles of the island, and an 1877 survey that covered the remainder of the island. The shorelines shown on these maps were compared to the shoreline shown on a map dated 1933. The position of the mean high water shoreline was measured every 1,000 feet along the island. The pre-project shoreline change rates for Bogue Banks are given in Table 7.2. Also given in this table are the average pre-project shoreline change rates for seven shoreline segments designated as Fort Macon, Atlantic Beach, Pine Knoll Shores, Indian Beach, East Emerald Isle, West Emerald Isle, and the Bogue Inlet Area. The limits of each shoreline segment are shown on Figure 7.15. A plot of the pre-project shoreline change rates along the island is given on Figure 7.16.

7.25. The Fort Macon Shoreline was experiencing a rather high rate of accretion during the pre-project period, averaging 9.6 feet/year. This accretion was associated with a developing sand spit that was growing in an easterly direction into Beaufort Inlet. The shoreline fronting the Town of Atlantic Beach was also accreting, but at a much slower rate of 1.4 feet/year. Beginning at a point approximately one mile west of the west town

Table 7.2 Bogue Banks - Pre-Project and With-Project Shoreline Change Rates and Difference in Rates

(Pre-Project rates based on comparison of 1854/77 and 1933 Maps)
(With-Project rates based on comparison of 1978 and 2001 profile surveys)

Baseline Station (feet)	Baseline Station (miles)	Pre-Project 1877 to 1933 **1854 to 1933 in bold** (feet/year)	Average Pre-Project Rate Shoreline Change for Segment (ft/yr)	With-Project 1978 to 2001 rate of change (ft/yr)	Average With-Project Rate Shoreline Change for Segment (ft/yr)	Difference in pre & post proj rates (ft/yr)	Average Difference in pre & post proj rates (ft/yr)	
4500	0.85	**13.1**		-2.7		-15.8		
5500	1.04	**12.2**		-10.4		-22.6		
6500	1.23	**10.9**	**9.6**	-9.3	**-8.8**	-20.2	**-18.4**	**Fort Macon**
7500	1.42	**9.7**		-13.1		-22.8		
8500	1.61	**7.0**		-13.1		-20.2		
9500	1.80	**4.7**		-4.3		-9.0		
10500	1.99	**2.3**		2.7		0.4		
11500	2.18	**0.2**		4.8		4.6		
12500	2.37	**-0.3**		4.5		4.8		
13500	2.56	**0.8**		5.1		4.3		
14500	2.75	**2.2**		6.1		4.0		
15500	2.94	**3.4**		6.5		3.0		
16500	3.13	**3.6**		6.4		2.8		
17500	3.31	**2.9**		4.6		1.7		**Atlantic Beach**
18500	3.50	**3.3**	**1.4**	5.4	**4.9**	2.1	**3.4**	
19500	3.69	**2.6**		5.6		3.0		
20500	3.88	**1.6**		3.9		2.3		
21500	4.07	**1.3**		5.3		4.0		
22500	4.26	**1.0**		5.2		4.2		
23500	4.45	**0.6**		6.2		5.6		
24500	4.64	**1.0**		5.5		4.5		
25500	4.83	**1.5**		5.9		4.4		
26500	5.02	**0.9**		5.5		4.6		
27500	5.21	1.3		4.3		3.0		
28500	5.40	0.9		3.7		2.8		
29500	5.59	0.7		4.0		3.3		
30500	5.78	0.0		3.5		3.5		
31500	5.97	-0.2		2.5		2.6		
32500	6.16	0.4		0.7		0.3		
33500	6.34	-0.9		-0.2		0.7		
34500	6.53	-1.2		-0.5		0.6		
35500	6.72	-0.7		-1.5		-0.8		
36500	6.91	-0.9		-2.9		-2.0		
37500	7.10	-1.8		-4.3		-2.5		
38500	7.29	-1.8		-2.6		-0.9		
39500	7.48	-1.8		-1.3		0.4		
40500	7.67	-1.8		-2.6		-0.8		
41500	7.86	-1.8		-2.7		-0.9		
42500	8.05	-1.6		-2.7		-1.1		
43500	8.24	-2.1		-3.0		-0.9		**Pine Knoll Shores**
44500	8.43	-2.2	**-2.3**	-3.2	**-2.6**	-1.0	**-0.3**	
45500	8.62	-1.8		-3.2		-1.4		
46500	8.81	-2.5		-3.2		-0.7		
47500	9.00	-2.7		-2.3		0.4		
48500	9.19	-2.9		-1.6		1.3		
49500	9.38	-3.1		-2.1		1.0		
50500	9.56	-2.7		-2.1		0.5		
51500	9.75	-3.3		-2.8		0.5		
52500	9.94	-3.1		-2.8		0.4		
53500	10.13	-3.1		-3.4		-0.2		
54500	10.32	-3.6		-3.4		0.2		
55500	10.51	-3.6		-3.1		0.4		
56500	10.70	-3.3		-3.1		0.2		
57500	10.89	-3.1		-3.9		-0.8		
58500	11.08	-3.3		-4.6		-1.3		
59500	11.27	-3.5		-4.3		-0.8		
60500	11.46	-3.1		-3.3		-0.2		

Table 7.2 (Continued)

Baseline Station (feet)	Baseline Station (miles)	Pre-Project 1877 to 1933 **1854 to 1933 in bold** (feet/year)	Average Pre-Project Rate Shoreline Change for Segment (ft/yr)	With-Project 1978 to 2001 rate of change (ft/yr)	Average With-Project Rate Shoreline Change for Segment (ft/yr)	Difference in pre & post proj rates (ft/yr)	Average Difference in pre & post proj rates (ft/yr)	
61500	11.65	-3.0		-3.2		-0.2		
62500	11.84	-2.2		-3.2		-1.0		
63500	12.03	-1.8		-3.2		-1.4		
64500	12.22	-1.5	**-1.2**	-3.5	**-3.1**	-2.0	**-1.9**	**Indian Beach**
65500	12.41	-0.4		-3.3		-2.9		
66500	12.59	-0.6		-3.4		-2.7		
67500	12.78	0.0		-2.5		-2.5		
68500	12.97	0.0		-2.6		-2.6		
69500	13.16	0.3		-2.4		-2.7		
70500	13.35	0.0		-2.2		-2.2		
71500	13.54	2.2		-2.3		-4.5		
72500	13.73	1.8		-2.5		-4.3		
73500	13.92	2.5		-2.5		-5.0		
74500	14.11	1.8		-2.6		-4.4		
75500	14.30	0.7		-2.5		-3.2		
76500	14.49	0.7		-2.1		-2.8		
77500	14.68	0.9		-2.5		-3.3		
78500	14.87	0.2		-2.8		-3.0		
79500	15.06	0.0	**0.6**	-3.6	**-2.6**	-3.6	**-3.2**	**East Emerald Isle**
80500	15.25	0.0		-3.7		-3.7		
81500	15.44	-0.2		-3.5		-3.3		
82500	15.63	0.1		-3.2		-3.3		
83500	15.81	-0.2		-3.2		-3.0		
84500	16.00	0.0		-4.0		-4.0		
85500	16.19	0.0		-3.4		-3.4		
86500	16.38	0.9		-2.5		-3.4		
87500	16.57	0.9		-1.7		-2.6		
88500	16.76	0.4		-1.8		-2.2		
89500	16.95	0.4		-1.2		-1.6		
90500	17.14	0.4		-1.4		-1.9		
91500	17.33	-0.4		-1.8		-1.4		
92500	17.52	0.0		-2.6		-2.6		
93500	17.71	0.4		-1.8		-2.3		
94500	17.90	0.4		-0.7		-1.1		
95500	18.09	0.4		-0.2		-0.7		
96500	18.28	0.4		-0.2		-0.6		
97500	18.47	0.0		-0.2		-0.2		
98500	18.66	0.0		-0.3		-0.3		
99500	18.84	-0.4		-0.5		-0.1		
100500	19.03	-0.9		-1.3		-0.4		
101500	19.22	-0.9		-1.8		-0.9		
102500	19.41	0.0		-1.0		-1.0		
103500	19.60	1.6		-1.0		-2.7		
104500	19.79	1.1	**0.3**	-0.5	**-1.3**	-1.5	**-1.6**	**West Emerald Isle**
105500	19.98	0.4		-0.7		-1.1		
106500	20.17	0.0		-0.9		-0.9		
107500	20.36	0.0		-1.3		-1.3		
108500	20.55	0.7		-2.2		-2.9		
109500	20.74	-0.2		-2.3		-2.1		
110500	20.93	0.4		-2.5		-3.0		
111500	21.12	0.7		-2.7		-3.4		
112500	21.31	0.7		-2.4		-3.1		
113500	21.50	1.3		-1.4		-2.7		
114500	21.69	1.4		-1.5		-2.9		
115500	21.88	-0.3		-1.2		-0.9		
116500	22.06	0.0		-1.5		-1.5		
117500	22.25	0.4		-2.0		-2.5		
118500	22.44	-0.1		-2.0		-1.9		
119500	22.63	0.7		-1.6		-2.3		
120500	22.82	1.0		-1.4		-2.4		
121500	23.01	2.0		-0.7		-2.7		
122500	23.20	2.7		0.2		-2.5		
123500	23.39	2.5		1.8		-0.7		
124500	23.58	2.7	**4.0**	2.7	**3.8**	0.1	**-0.3**	**Bogue Inlet Area**
125500	23.77	4.1		4.4		0.3		
126500	23.96	3.2		5.7		2.4		
127500	24.15	4.3		8.1		3.8		
128500	24.34	4.1		11.6		7.5		
129500	24.53	4.1		20.2		16.1		
130500	24.72	8.2		18.2		9.9		
131500	24.91	20.5		-8.4		-29.0		

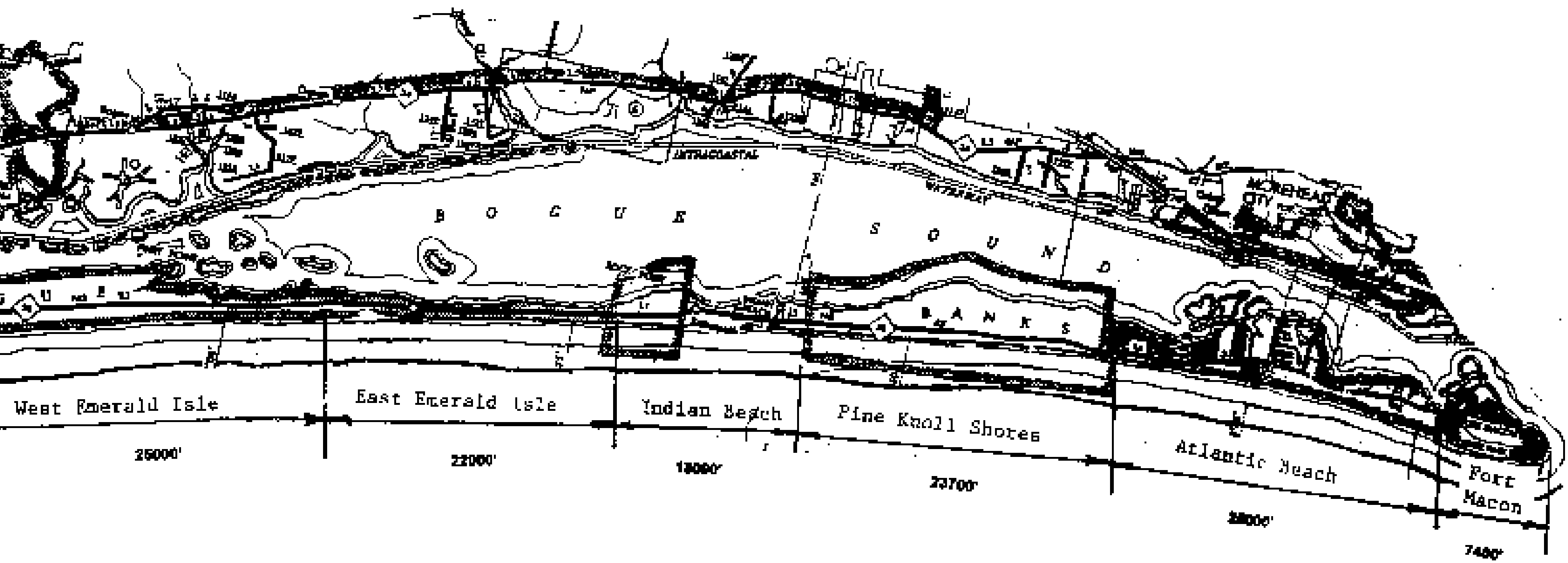
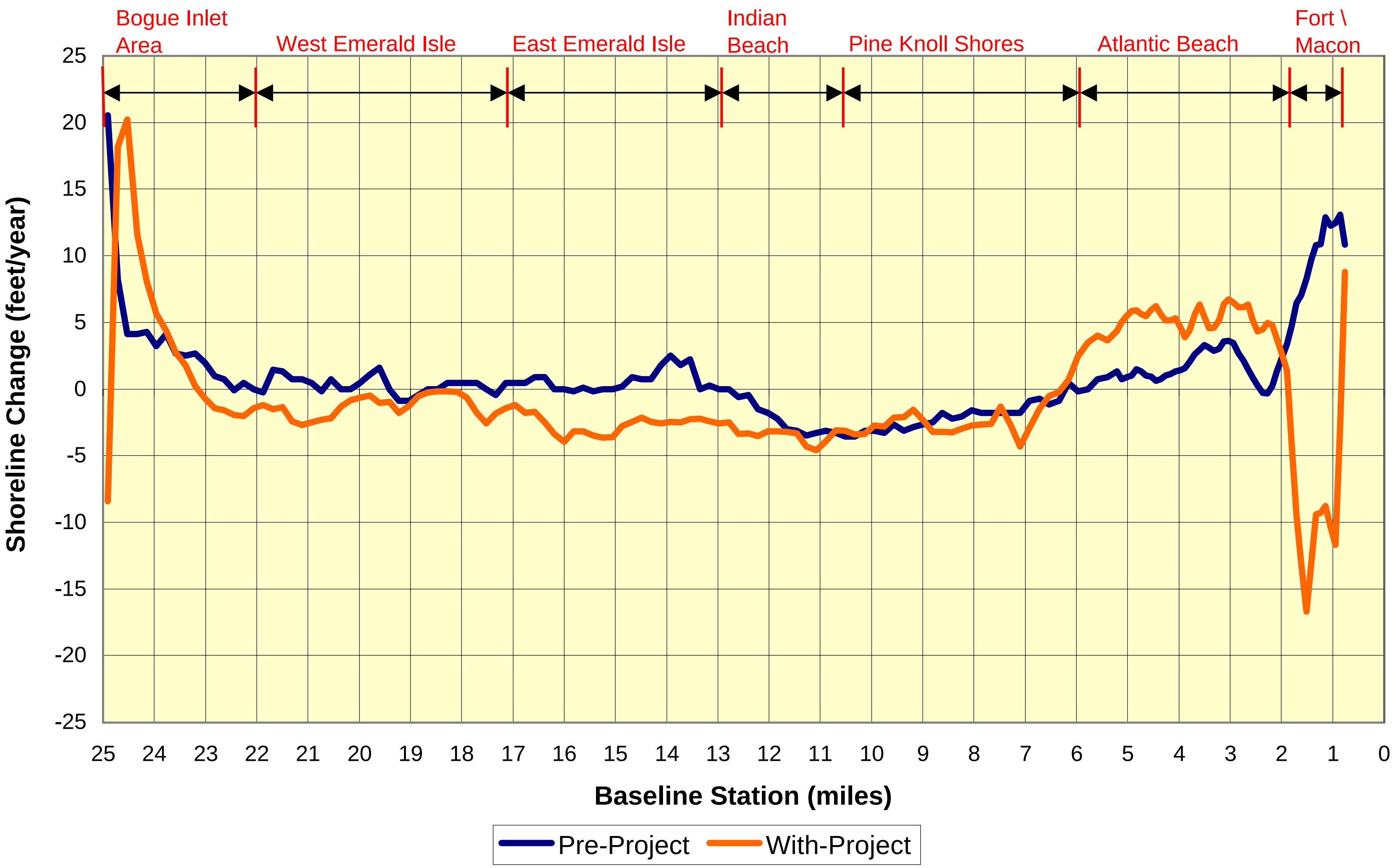


Figure 7.1

Shoreline

Figure 7.16 Bogue Banks Pre-Project and With-Project Shoreline Change Rates



1978 2001 surveys
plot pre and post rates

limits of Atlantic Beach and continuing for a distance of approximately 5 miles, the pre-project shoreline was experiencing significant erosion ranging from 1.8 to 3.6 feet/year (see Figure 7.16). This erosion zone encompassed most of the Town of Pine Knoll Shores and about one-half of the shoreline of Indian Beach. The average shoreline change rate for the entire shoreline fronting Pine Knoll Shores was –2.3 feet/year while the Indian Beach shoreline had an average erosion rate of –1.2 feet/year. Both the East Emerald Isle and West Emerald Isle shoreline segments were generally accreting with average accretion rates of 0.6 feet/year for East Emerald Isle and 0.3 feet/year for West Emerald Isle. The Bogue Inlet Area, which covers the westernmost 3.0 miles of the island, was accreting at an average rate of 4.0 feet/year with much higher accretion rates occurring close to Bogue Inlet. The changes on the west end of Bogue Banks are dominated by changes in the configuration of the ebb tide delta of Bogue Inlet.

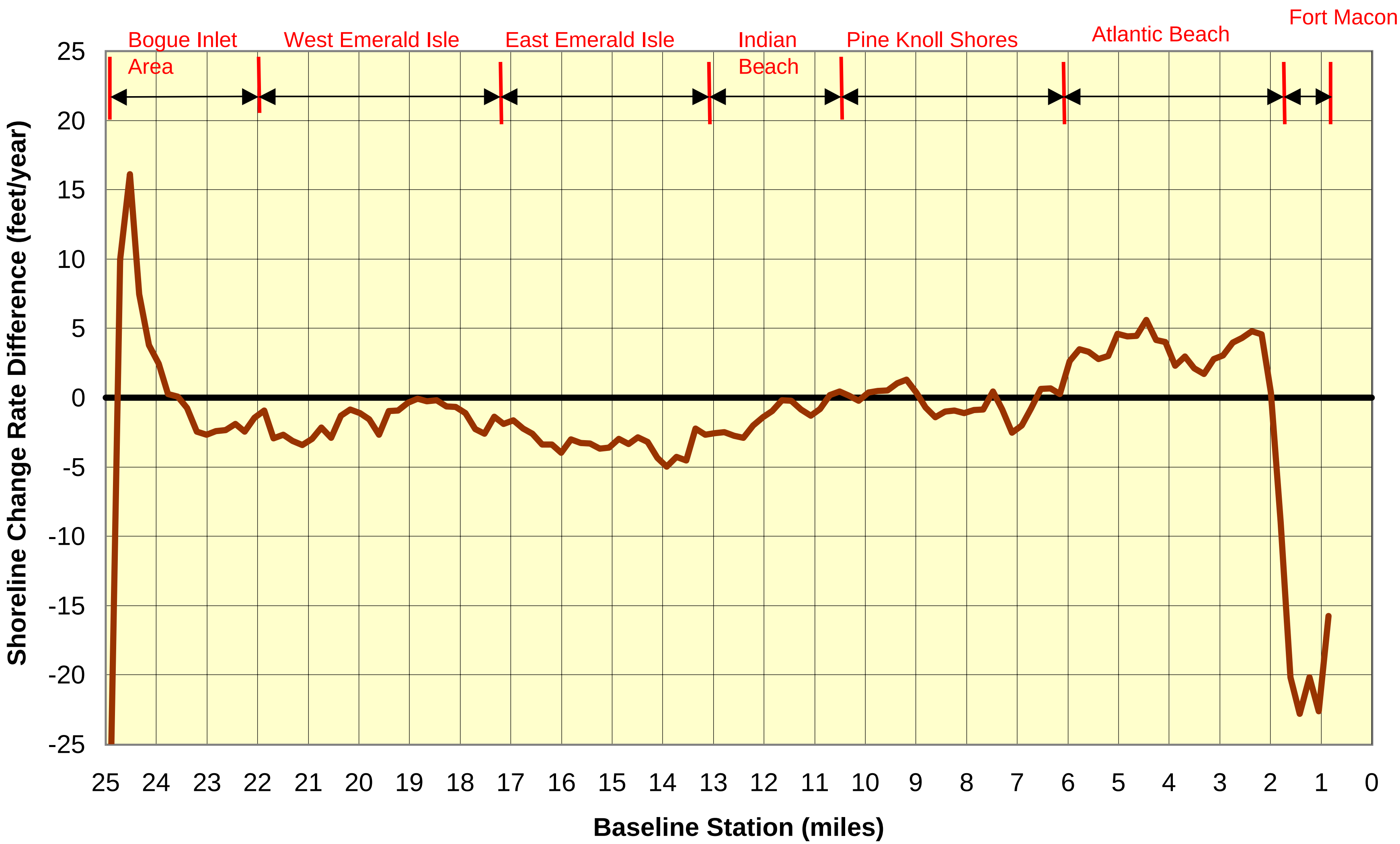
7.26. With-Project Shoreline Change Rates on Bogue Banks. The June 1978 beach profile survey of Bogue Banks covered the entire island with profile spacing of 1,000 feet over the first 6 miles west of Beaufort Inlet and profile spacings between 1,700 feet and 3,400 feet over the remainder of the island. The survey included the area from just landward of the Corps of Engineers baseline to wading depths (generally –4 to –5 feet msl). An April 2001 survey of the island included onshore and offshore profiles spaced at 1,000-foot intervals that extended from just landward of the Corps of Engineers baseline to approximately one mile offshore. The position of the +6.0-foot msl and 0-foot msl contours were determined from these two profile surveys with the average position of the two contours used to represent the shoreline position. Using the average position of these two contours to represent the position of the shoreline eliminated some of the bias that may have been caused by differences in the slope of the foreshore between the two surveys. In this regard, the average slope of the beach between the +6-foot msl and 0-foot msl contours was 1V: 17.6H for the April 1978 survey and 1V: 19.0H for the 2001 survey. These average beach slopes excluded the areas near Beaufort Inlet and Bogue Inlet that are influenced by the ebb tide deltas of these inlets. Comparative plots of the 1978 and 2001 surveys for selected profile stations are provided in Appendix A. Note that the profile stations for the 1978 and 2001 surveys are not necessarily the same in each plot, however, the profile stations are generally within 200 to 400 feet of each other and provide a reasonable image of the recent shoreline changes taking place on Bogue Banks.

7.27. Profile stations surveyed in 1978 differed from the profile stations surveyed in 2001, but in general, due to the 1,000-foot spacing of the 2001 profile stations, a 2001 profile was located within several feet to 400 feet of the 1978 profile location. In order to compare changes in shoreline position along the island, the position of the 2001 shoreline was estimated for each 1978 profile station by linear interpolation between two 2001-profile stations on either side of the 1978 profile station. While this procedure added another element of error to the analysis, the error is consider to be relatively small (of the order of +/- 10 feet) given the 1,000-foot profile spacing of the 2001 survey. Once the shoreline change rate was determined for every 1978 profile station, the data was further interpolated to provide estimated with-project shoreline change rates for the same 1,000-foot profile stations used in the pre-project shoreline change analysis. This is another source of error for the with-project rates, but owing to the uniformity of the shoreline change rates along the island, the probable error is of the order of +/- 0.5 foot/year for any one station and less than that for average changes over relatively long shoreline segments. The resulting with-project shoreline change rates for Bogue Banks are given in Table 7.2 and plotted on Figure 7.16 for comparison with the pre-project rates.

7.28. Discussion of Bogue Banks Pre-Project and With-Project Shoreline Change Differences. A plot of the differences in the rates of shoreline change between the pre-project period and the with-project period is given on Figure 7.17. During the with-project period (1978 to 2001), the shoreline fronting the Fort Macon State Park experienced what appeared to be an accelerated rate of erosion compared to the pre-project rate. However, the June 1978 survey was taken immediately following the disposal of material removed from the inner harbor during the construction of the 40-foot mlw project, therefore, the shoreline was situated well seaward of its normal location (see profiles 40+00 to 90+00 in Appendix A). As discussed later in the section addressing the performance of the beach disposals on Bogue Banks, the deposited material formed an inordinately wide beach with rather sharp transition angles, which combined to enhance the rate of sediment transport out of the deposition area. While additional material was placed on the Fort Macon shoreline in 1994, it too was excessively wide and eroded at a high rate. Accordingly, the apparent high rates of erosion along this segment of the Bogue Banks shoreline can be attributed to the poor performance of the fill rather than any project related impact. The shoreline fronting the Town of Atlantic Beach also received slightly less than 5 million cubic yards of beach compatible material from construction and maintenance activities associated with the harbor project during the with-project period. This accounts for the higher rate of accretion of its shoreline compared to the pre-project period. While the accretion of the Atlantic Beach shoreline was due to the disposal of dredged material from the Morehead City Harbor project, such disposal is an integral part of the operation and maintenance of the project. If the project is having an impact on Atlantic Beach shoreline, the disposal of the dredged material has provided more than adequate compensation or mitigation for this possible impact. Farther down the island, shoreline changes within the town limits of Pine Knoll Shores were essentially the same as the pre-project period, with an average erosion rate of –2.6 feet/year compared to the pre-project rate of –2.3 feet/year. The western portion of Bogue Banks, from about mile 12 (Indian Beach) to mile 23 (West Emerald Isle) has experienced a significant change in shoreline behavior. During the pre-project period, both East Emerald Isle and West Emerald Isle were accreting slightly while during the with-project period, the shorelines in these areas eroded. The Bogue Inlet area continued to experience accretion at approximately the same rate as during the pre-project period. The highest rate of accretion did shift about 0.5 mile to the east in response to the eastward movement of the ocean bar channel through the inlet. The eastward shift of the channel has causes significant erosion on the extreme west end of the island, which was recorded at the westernmost station during the with-project period.

7.29. Pine Knoll Shores, Indian Beach, East Emerald Isle, and to some extent West Emerald Isle experienced comparable average erosion rates during the 1978 to 2001 with-project period. While the average erosion rate for Pine Knoll Shores during the with-

Figure 7.17 Bogue Banks Difference in Pre-Project and With-Project Shoreline Change Rates



1978 2001 surveys
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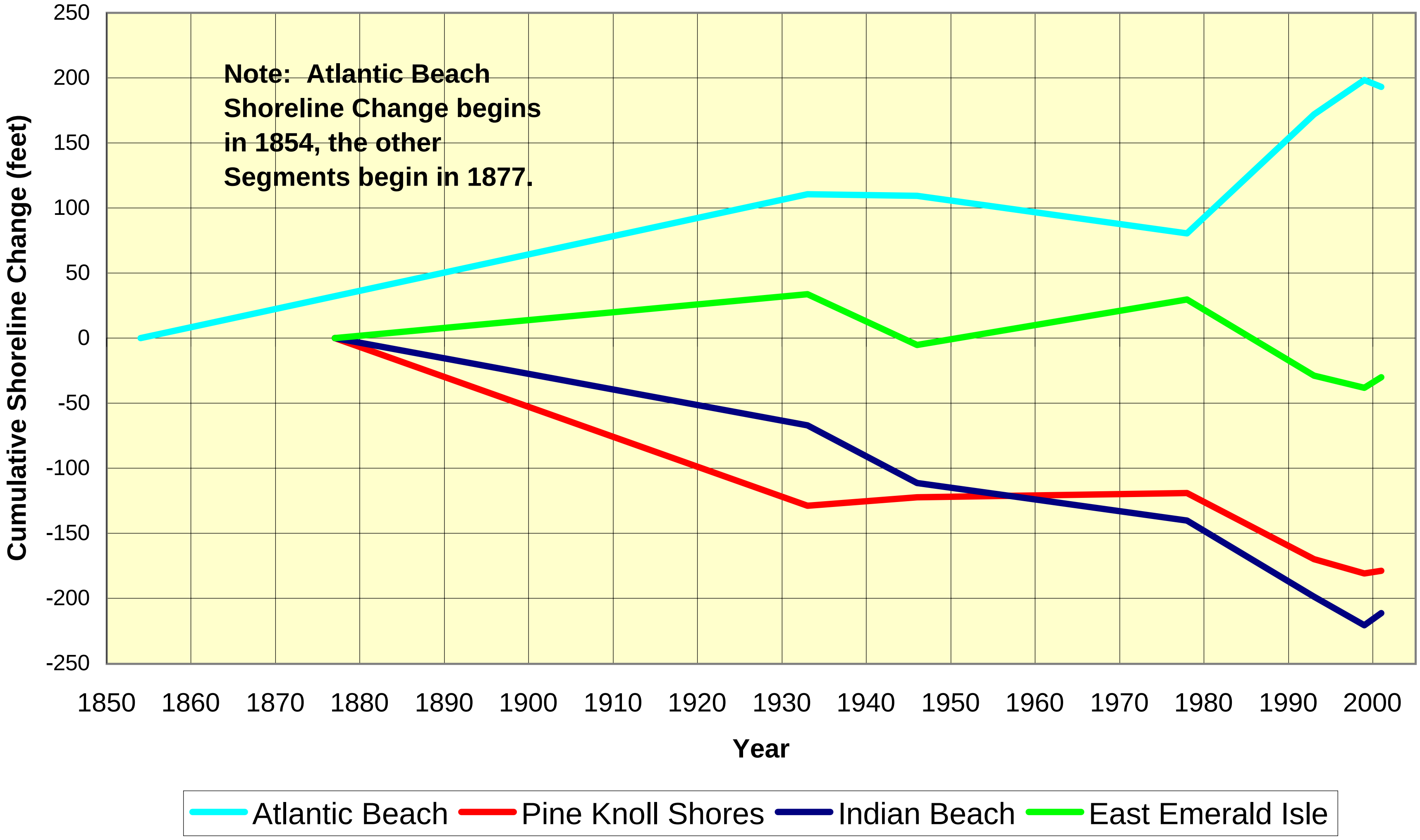
project period was essentially the same as the pre-project period, the other shoreline segments west of Pine Knoll Shores experienced significant changes in behavior. The potential sediment transport analysis, presented above, found no difference in sediment transport along Bogue Banks west of Pine Knoll Shores for the pre-project and with-project conditions. This, combined with the Pine Knoll Shores shoreline behaving in a similar manner for both the pre-project and with-project periods essentially eliminates the Morehead City Harbor project as a possible factor contributing to the change in shoreline response along these western segments. The erosion of these western segments during the with-project period, as well as the Pine Knoll Shores segment, was primarily associated with storm activity that reached a peak during the 1993 to 1999 period. Between 1993 and 1999, the Bogue Banks area was impacted by 12 tropical storm events, 7 of which were categorized as moderate to severe. The moderate to severe storms included Hurricane Emily in August 1993, Hurricane Gordon in November 1994, Tropical Storm Arthur in June 1996, Hurricane Bertha in July 1996, Hurricane Fran in September 1996, Hurricane Bonnie in August 1998, and Hurricane Floyd in September 1999. The most severe storm during this period appeared to be Hurricane Bonnie. During this 6-year period, the average annual Storm Intensity Factor (discussed previously) was 217.0 (see Table C-1 in Appendix C). For the entire 1978 to 2001 with-project period, the average annual Storm Intensity Factor was 137.7, which is slightly less than the average annual Storm Intensity Factor for the pre-project period, which was 175.7. However, during the last 21 years of the pre-project period (1915 to 1936) the average annual Storm Intensity Factor was only 82.6, which was indicative of relatively mild storm activity and would have allowed time for the shoreline to recover from the more intense storms that occurred during the early part of the pre-project period. Since the frequency and intensity of storms increased during the latter portion of the with-project period, the effects of the storms on the shoreline accumulated without the benefit of significant post-storm recovery. As a result, storm impacts on the shoreline were still present when the island was surveyed in April 2001 resulting in the observed erosion rates during the with-project period.

7.30. Bogue Banks Supplemental Shoreline Change Data. While the 1978 to 2001 time period was selected to represent the with-project period, additional shoreline change information was developed for Bogue Banks, which covered the period from 1933 to 2001. Shoreline positions shown on maps dated in 1933 and 1946 were digitized to a common horizontal datum and shoreline positions determined at 500-foot increments along Bogue Banks. The 1933 and 1946 maps did not cover West Emerald Isle or the Bogue Inlet Area. All shoreline positions were referenced to their distance from the Corps of Engineers baseline. The accuracy developed from these maps is of the same order as the maps used to develop the pre-project shoreline change rates. Shoreline positions were also determined every 500 feet along the entire length of Bogue Banks from a 1978 photo mosaic of Bogue Banks, made by the Corps of Engineers, and a 1993 orthophoto mosaic produced by the State of North Carolina. The shoreline on the mosaics was defined as the “wet-dry” line. The error associated with the shorelines shown on the mosaics was of the order of +/- 30 feet. A 1999 profile survey of all of Bogue Banks, conducted by CSE/Baird of Columbia, South Carolina for Carteret County, was used to determine the 1999 shoreline position. Tabulations of the shoreline change

Figure 7.18 Bogue Banks Cumulative Shoreline Changes 1854/77 to 2001



BB_Sediment_Budget_Master_List.xls
plot 1800's to 01 bogue sl ch

rates together with plots of the shoreline change rates along Bogue Banks for the 1933 to 1946, 1946 to 1978, 1978 to 1993 and 1993 to 1999 time periods are given in Appendix A.

7.31. The supplemental shoreline change information was combined with the pre-project and with-project data presented above to develop cumulative shoreline change curves for Atlantic Beach, Pine Knoll Shores, Indian Beach, and East Emerald Isle between 1854/77 and 2001. A plot of the cumulative shoreline change curves for the four beach segments is shown on Figure 7.18. As noted on Figure 7.18, the cumulative plot for Atlantic Beach begins in 1854 while the cumulative plot for the other beach segments begins in 1877. Between 1933 and 1978, the shoreline of Atlantic Beach, Pine Knoll Shores, and East Emerald Isle were fairly stable while Indian Beach experienced some significant erosion during this period. Between 1978 and 2001, the Atlantic Beach shoreline accreted in response to the beach disposal operations in 1986 and 1994 while the other three beach segments began to experience accelerated erosion. The increased erosion rates that were determined for Pine Knoll Shores, Indian Beach, and East Emerald Isle between 1978 and 2001 were not unlike shoreline change rates experienced during other periods. For example, the cumulative shoreline change plots on Figure 7.18 demonstrate that the Pine Knoll Shores and Indian Beach shorelines have been generally eroding throughout the entire 124-year period (1877 to 2001) while the East Emerald Isle shoreline has had a history of alternating periods of accretion and erosion with the net change over the 124-year period being erosion. Pine Knoll Shores did experience a period of relative stability between 1933 and 1978; however, the shoreline change rate determined for the 1978 to 2001 period was not significantly different than the rate determined for the pre-project period (1877 to 1933). As was mentioned earlier in the discussion of the shoreline changes during the with-project period (1978 to 2001), all three segments west of Atlantic Beach eroded at similar rates. The uniform response of the three segments during the 1978 to 2001 time period was attributed to storm activity. During the last two years of the analysis period, 1999 to 2001, the three beach segments seemed to be experiencing some post-storm recovery while the Atlantic Beach shoreline eroded slightly.

7.32. Pre-Project Shoreline Changes on Shackleford Banks. Pre-project shoreline changes for Shackleford Banks were obtained by comparing the shoreline positions every 500 feet along the island using maps dated in 1853 and 1946. Obviously, the 1946 shoreline map was made approximately 10 years following the initiation of major improvements for Morehead City Harbor, however, since the total period covered by the maps was 93 years, any impacts of the harbor project on Shackleford Banks during the latter 10-years of this period would have been minor. Shoreline change rates for Shackleford Banks for the 1853 to 1946 period are given in Table 7.3 and are plotted on Figure 7.19. During the pre-project period, the island was eroding along its entire length except for a small area located immediately west of Barden Inlet. The highest rate of erosion was -7.8 feet/year at baseline stations 375+00 and 380+00 located near Beaufort Inlet. The pre-project shoreline behavior seemed to divide the island into three segments, namely; an eastern segment situated between baseline stations 10+00 and 100+00, a middle segment between baseline stations 100+00 and 300+00, and a western segment

Table 7.3 Shackleford Banks - Pre-Project and With-Project Shoreline Change Rates and Difference in Rates

(Pre-Project rates based on comparison of 1854 and 1946 maps.)
(With-Project rates based on comparison of 1980 and 2000 profile surveys)

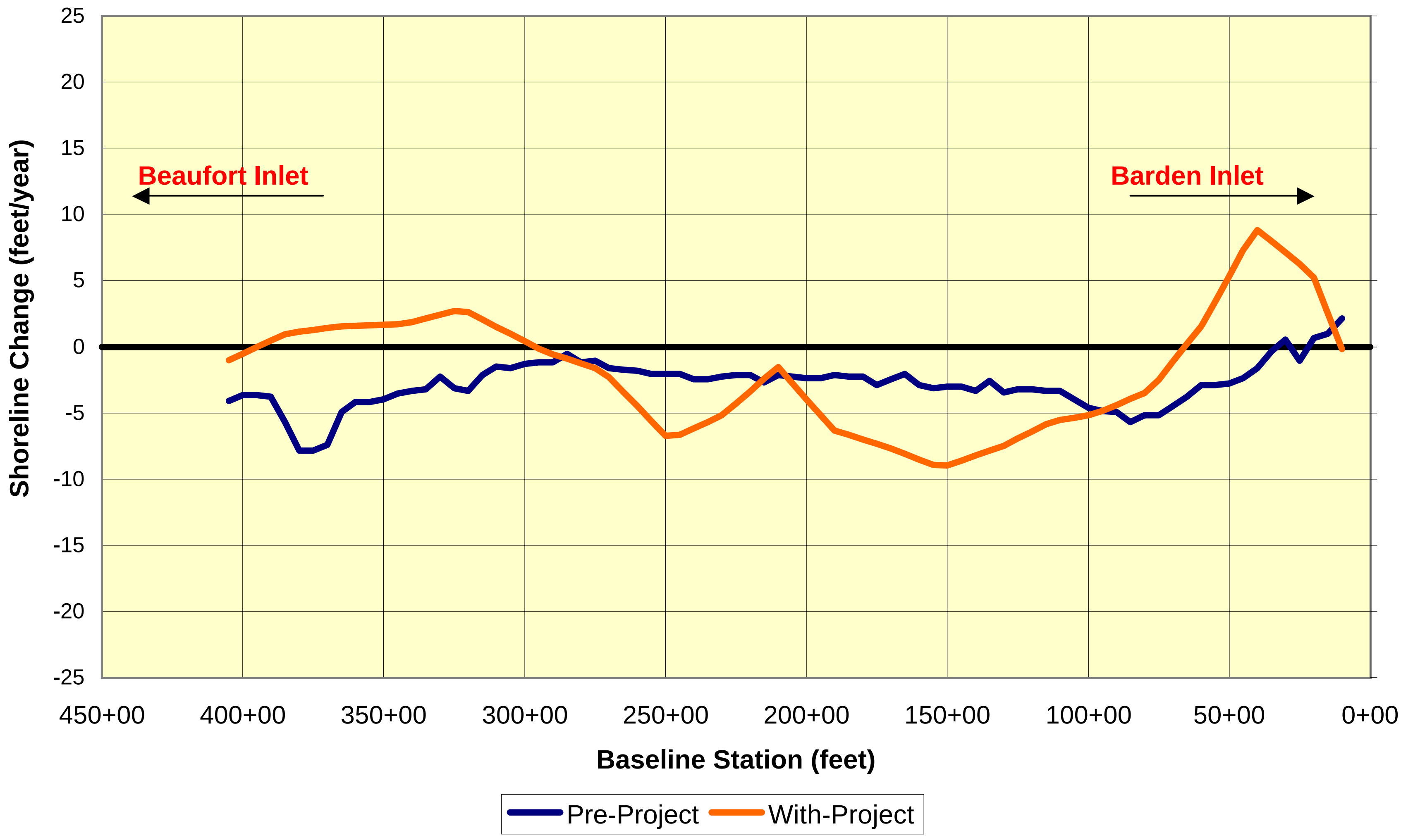
Station	Pre-Project Rate of Shoreline Change 1854 to 1946 ft/yr	Average Pre-Project Rate of SL Change for Segment ft/yr	With-Project Rate of Shoreline Change 1980 to 2000	Average With-Project Rate of SL Change for Segment ft/yr	Difference in Shoreline Change Rate Pre vs.With ft/yr	Average Difference in Pre & With Project Rates ft/yr	
10+00	2.2		-0.2		-2.3		
15+00	1.0		2.5		1.6		
20+00	0.6		5.2		4.6		
25+00	-1.1		6.3		7.3		
30+00	0.5		7.1		6.6		
35+00	-0.3		8.0		8.3		
40+00	-1.6		8.8		10.4		
45+00	-2.4		7.3		9.7		
50+00	-2.8		5.3		8.1		
55+00	-2.9	**-2.5**	3.4	**1.6**	6.3	**4.1**	**Eastern Segment**
60+00	-2.9		1.6		4.5		
65+00	-3.8		0.2		4.0		
70+00	-4.5		-1.1		3.4		
75+00	-5.2		-2.5		2.7		
80+00	-5.2		-3.5		1.7		
85+00	-5.7		-4.0		1.7		
90+00	-4.9		-4.4		0.5		
95+00	-4.8		-4.9		0.0		
100+00	-4.6		-5.2		-0.5		
105+00	-4.0		-5.4		-1.4		
110+00	-3.3		-5.6		-2.2		
115+00	-3.3		-5.9		-2.5		
120+00	-3.2		-6.4		-3.2		
125+00	-3.2		-6.9		-3.7		
130+00	-3.4		-7.5		-4.0		
135+00	-2.6		-7.9		-5.3		
140+00	-3.3		-8.2		-4.9		
145+00	-3.0		-8.6		-5.6		
150+00	-3.0		-9.0		-6.0		
155+00	-3.1		-8.9		-5.8		
160+00	-2.9		-8.5		-5.6		
165+00	-2.0		-8.1		-6.1		
170+00	-2.5		-7.7		-5.2		
175+00	-2.9		-7.3		-4.4		
180+00	-2.3		-7.0		-4.7		
185+00	-2.3		-6.7		-4.4		
190+00	-2.2		-6.3		-4.2		
195+00	-2.4		-5.2		-2.8		
200+00	-2.4		-4.0		-1.6		
205+00	-2.3	**-2.3**	-2.7	**-5.1**	-0.5	**-2.8**	**Middle Segment**
210+00	-2.2		-1.5		0.6		

Table 7.3 (Continued)

Station	Pre-Project Rate of Shoreline Change 1854 to 1946 ft/yr	Average Pre-Project Rate of SL Change for Segment ft/yr	With-Project Rate of Shoreline Change 1980 to 2000	Average With-Project Rate of SL Change for Segment ft/yr	Difference in Shoreline Change Rate Pre vs.With ft/yr	Average Difference in Pre & With Project Rates ft/yr	
215+00	-2.7		-2.4		0.3		
220+00	-2.2		-3.4		-1.2		
225+00	-2.2		-4.3		-2.2		
230+00	-2.3		-5.2		-2.9		
235+00	-2.5		-5.7		-3.2		
240+00	-2.5		-6.2		-3.7		
245+00	-2.0		-6.7		-4.6		
250+00	-2.0		-6.7		-4.7		
255+00	-2.0		-5.6		-3.6		
260+00	-1.8		-4.5		-2.7		
265+00	-1.7		-3.4		-1.7		
270+00	-1.6		-2.3		-0.7		
275+00	-1.1		-1.6		-0.5		
280+00	-1.2		-1.3		-0.1		
285+00	-0.5		-0.9		-0.4		
290+00	-1.2		-0.6		0.6		
295+00	-1.2		-0.1		1.0		
300+00	-1.3		0.4		1.7		
305+00	-1.6		1.0		2.6		
310+00	-1.5		1.5		3.0		
315+00	-2.2		2.1		4.2		
320+00	-3.3		2.6		6.0		
325+00	-3.1		2.7		5.8		
330+00	-2.3		2.4		4.7		
335+00	-3.2		2.2		5.4		
340+00	-3.3		1.9		5.2		
345+00	-3.5		1.7		5.2		
350+00	-4.0		1.7		5.6		
355+00	-4.2	**-4.1**	1.6	**1.3**	5.8	**5.4**	**Western Segment**
360+00	-4.2		1.6		5.8		
365+00	-4.9		1.5		6.5		
370+00	-7.4		1.4		8.8		
375+00	-7.8		1.3		9.1		
380+00	-7.8		1.2		9.0		
385+00	-5.7		1.0		6.7		
390+00	-3.8		0.5		4.2		
395+00	-3.7		0.0		3.6		
400+00	-3.7		-0.5		3.1		
405+00	-4.1		-1.0		3.1		
Ave all stas.	**-2.8**		**-1.8**		**1.0**		

Shack SL 79 to 2000.xls
compare data pre-post

Figure 7.19 Shackleford Banks Pre-Project and With-Project Shoreline Change Rates



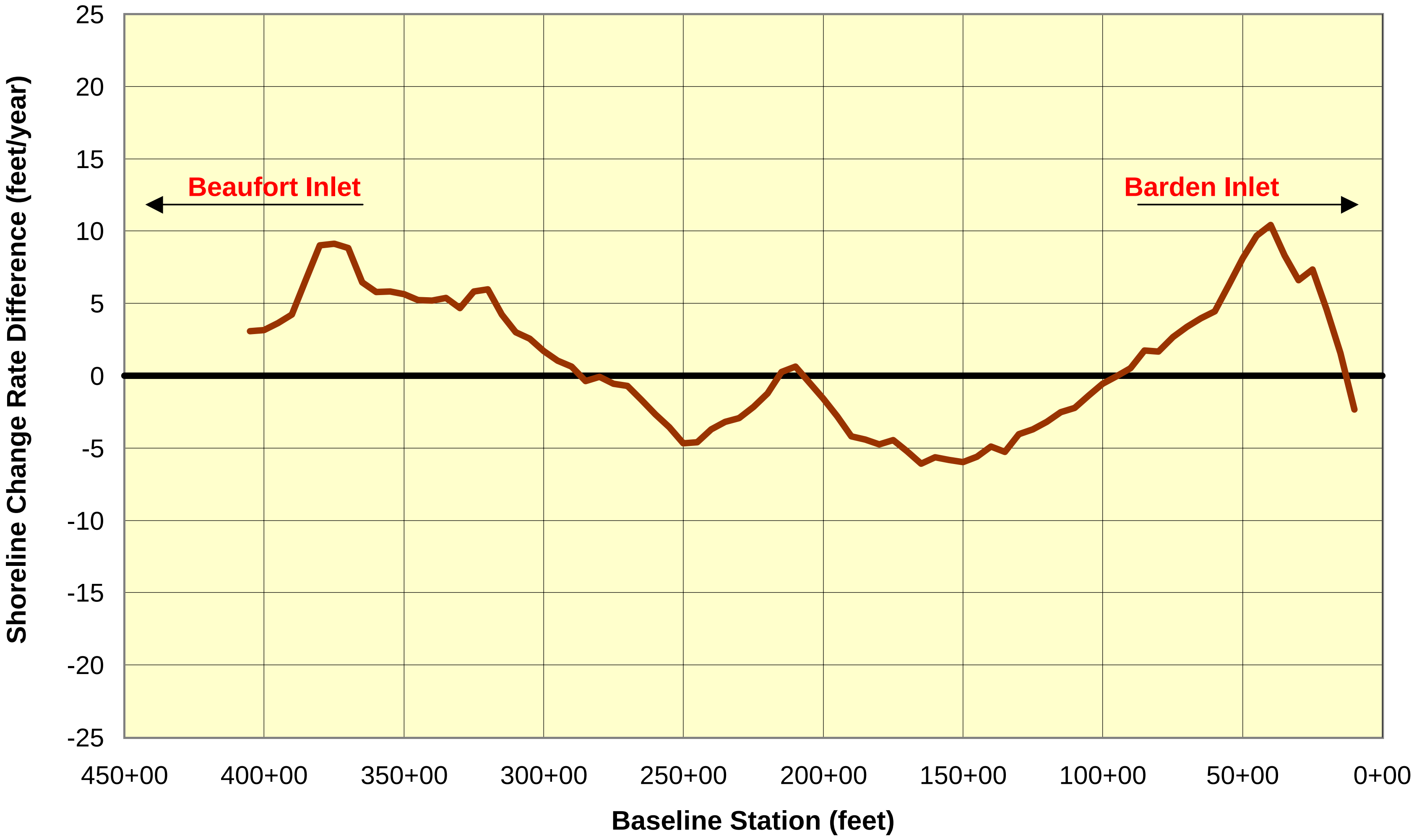
Shack SL 79 to 2000.xls
Plot Shack Pre-Post SL rates

between baseline stations 300+00 and 405+00. Note that the present-day island extends another 5,000 feet to west. As discussed earlier, the westward extension of the island began in 1936 following the construction of the ocean entrance channel of Beaufort Inlet along a fixed alignment and continued until 1974. For the pre-project period, the average shoreline change rate in the eastern segment of Shackleford Banks averaged –2.5 feet/year while the average rate of change for the middle and western segments were –2.5 feet/year and –4.1 feet/year respectively. For the entire island, the average pre-project shoreline change rate was –2.8 fee/year.

7.33. With-Project Shoreline Changes on Shackleford Banks. Profile surveys of Shackleford Banks taken in July 1980 and October 2000 were used to determine changes in the shoreline position for the with-project condition. As was the case for the Bogue Banks surveys, the shoreline position for each survey and each profile station was computed as the average position of the +6-foot msl and 0+foot msl contours to compensate for possible slope differenced between the surveys. In this regard, the average slope of the beach between the +6-foot msl and 0-foot msl contours was 1V: 17.6H for the July 1980 survey and 1V: 14.5H for the October 2000 survey. Profile stations on Shackleford Banks are located approximately 2,000 feet apart. In order to compare the with-project shoreline changes with the pre-project changes, the rate of shoreline change was interpolated every 500 feet to match the same stations used in the pre-project shoreline change analysis. The resulting shoreline change rates are given in Table 7.3 and plotted on Figure 7.19 for comparison with the pre-project rates. During the with-project period, the middle segment of the island experienced significant erosion, averaging –5.1 feet/year while the eastern and western segments accreted at rates of 1.6 feet/year and 1.3 feet/year respectively. For the entire island, the average shoreline change rate was –1.8 feet/year.

7.34. Discussion of Shackleford Banks Pre-Project and With-Project Shoreline Change Differences. A plot of the differences in the rates of shoreline change on Shackleford Banks for the pre-project and with project periods is given on Figure 7.20. During the with-project period, the west end of Shackleford Banks experienced a considerable amount of accretion while the middle segment eroded at rate more than twice that of the pre-project rate. The eastern segment near Barden Inlet also accreted a significant amount. The overall result of these changes in shoreline behavior has been an increase the concavity of the island's planform. The accretion on the west end of the island corresponds to the area where the ebb tide delta depth contours join the shore parallel depth contours off Shackleford Banks (see Figure 4.1). Similar shoreline response has been documented at other inlets where a seaward bulge in the shoreline is generally present in this area. In the case of the other inlets, however, ebb tide delta channel tends to migrate from one side of the inlet to the other and in-so-doing, changes the location where the ebb tide delta contours merge with the island contours. As a result, the characteristic shoreline bulge at these other inlets is ephemeral and moves from one area to another. In the case of Beaufort Inlet however, the ebb tide delta attachment point has not changed appreciable since 1952. The permanency of the ebb tide delta attachment point combined with the accompanying wave refraction patterns associated with the reconfigured ebb tide delta has led to the restructuring of the island's planform.

Figure 7.20 Shackleford Banks Difference in Pre-Project and With-Project Shoreline Change Rates



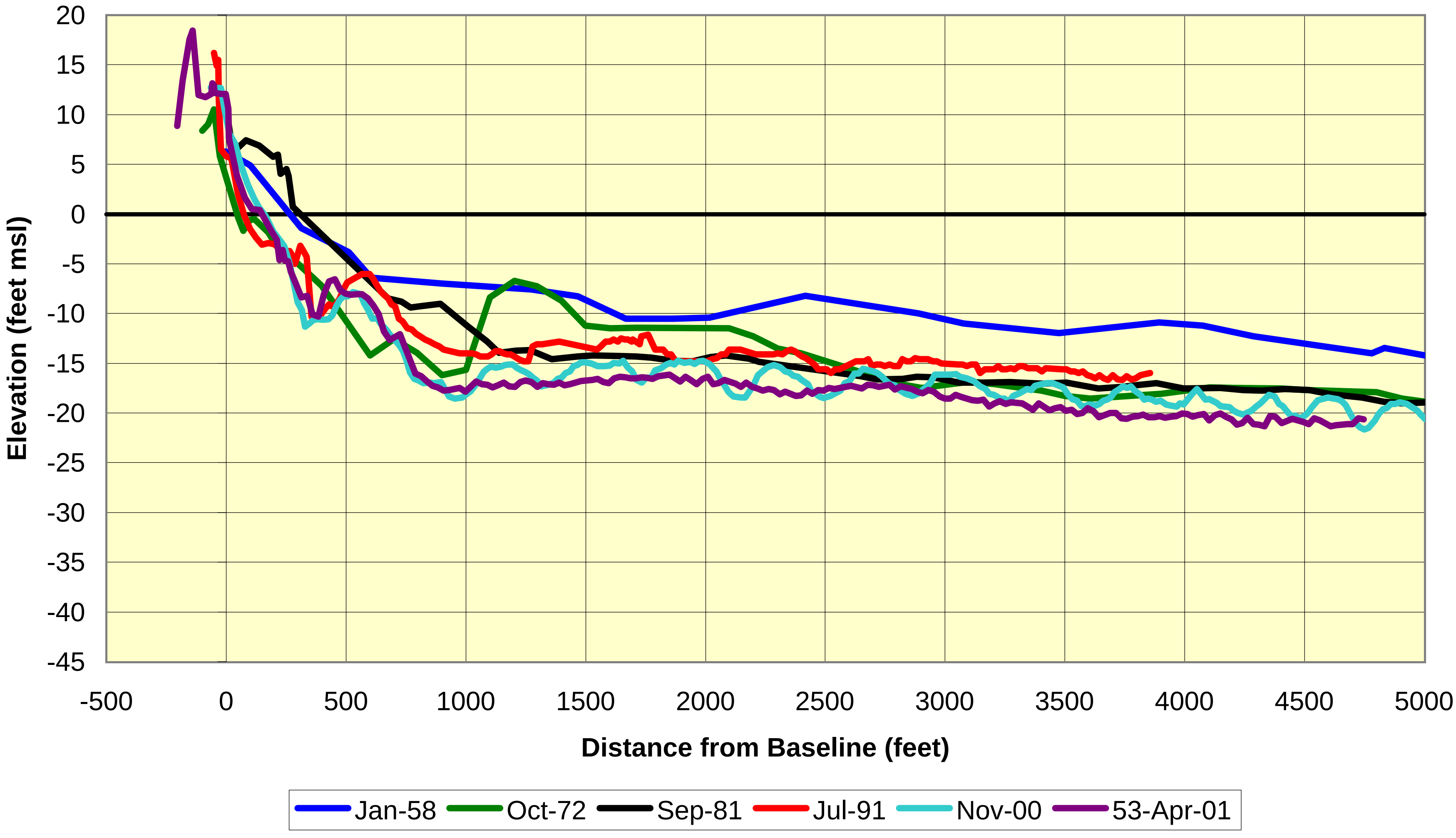
Shack SL 79 to 2000.xls
plot diff pre-post

The accretion that has occurred on the east end of the island near Barden Inlet is due to a similar phenomenon, however, this area is much more complex due to the presence of Cape Lookout and the Cape Lookout Bight. While the middle portion of Shackleford Banks is presently eroding at a rate more than twice that of the pre-project rate, the average erosion rate for the entire island is 1.0 foot/year less than the pre-project rate.

7.35. Offshore Changes-Bogue Banks. The eastern 5.5 miles of Bogue Banks has been covered by offshore surveys since 1958. Plots of the offshore surveys made in January 1958, October 1972, September 1981, July 1991, November 2000, and April 2001 for selected profile stations are shown on Figures 7.21 to 7.28. The selected profile stations are spaced at intervals between 3,000 and 4,000 feet and correspond to the profile stations surveyed in 1958. The offshore profiles indicate that the near shore area off this section of Bogue Banks is getting deeper. The most significant depth changes were recorded between January 1958 and October 1972 at baseline stations 50+00, 70+00, and 100+00. These three profile lines cut across the west side of the Beaufort Inlet ebb tide delta and reflect the deepening or deflation of the delta that has been observed since 1952. The near shore portions of the September 1981 profiles at stations 50+00 and 70+00 show the effects of the 1978 beach disposal operation on the Fort Macon shoreline. At station 100+00 (Figure 7.23), the November 2000 and April 2001 surveys picked up a portion of the near shore disposal mound created by the placement of the dredged material from the ocean bar channel since 1997. Station 140+00 is located near the area where the depth contours of the Beaufort Inlet ebb tide delta merge with the shore parallel contours off the east end of Bogue Banks. The profiles taken at this station show a rather gradual but persistent deepening over time. The effects of the 1986 beach disposal operation that occurred between baseline stations 100+00 and 290+00 and the 1994 disposal operation between baseline stations 210+00 and 318+00 are evident on the near shore portion of the profiles within these disposal areas. Based on a comparison of the September 1981 and July 1991 profiles, the material placed on the beach in 1986 appeared to close with the pre-filled profile in depths ranging from 25 to 35 below msl. Notwithstanding the fills, the offshore portions of the profiles continued to deepen as evidenced by the April 2001 survey.

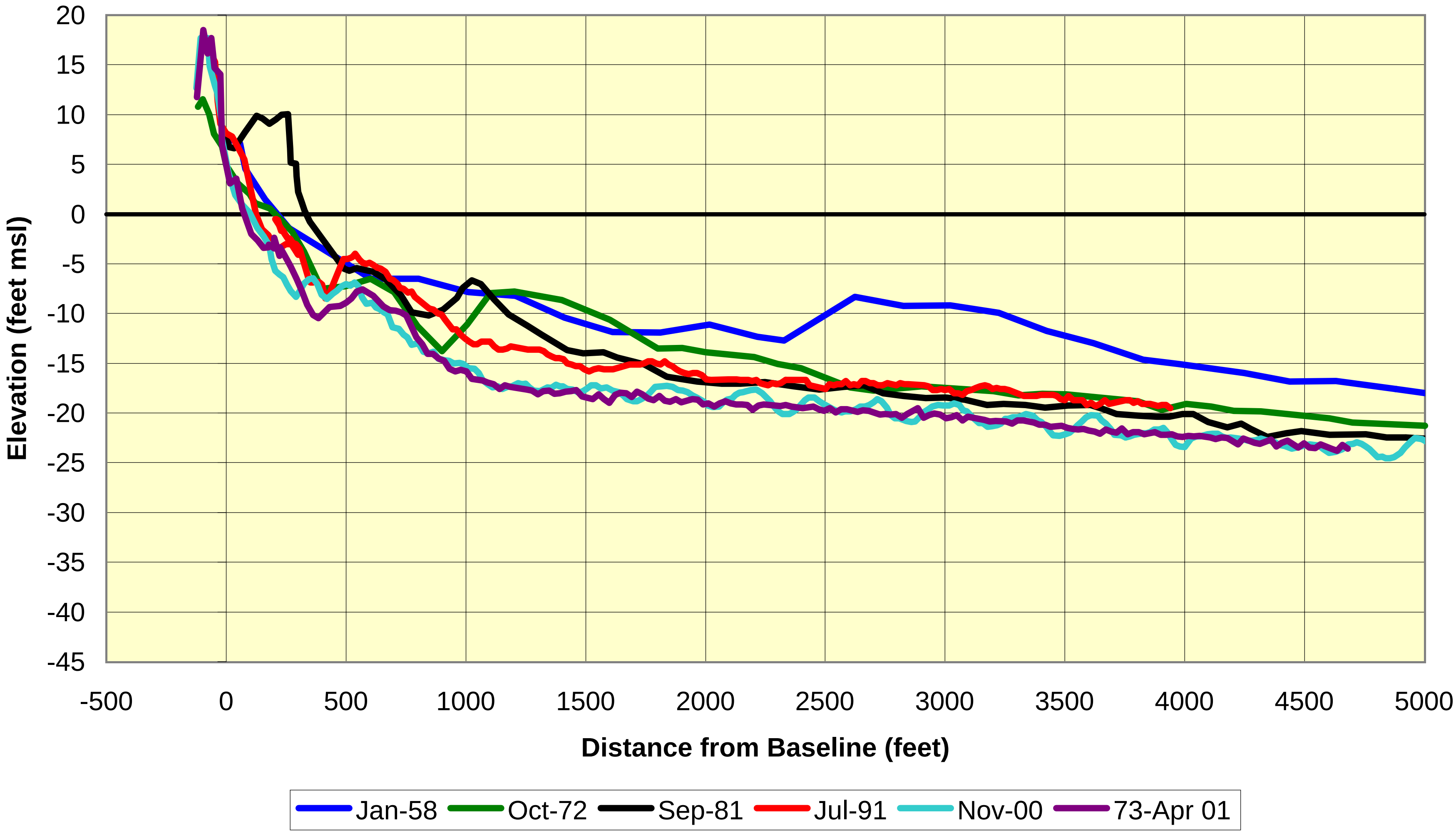
7.36. The offshore profiles were used to determine the volume change along the eastern 5.5 miles of Bogue Banks (Atlantic Beach and Fort Macon State Park) between 1958 and 2001. The volume change computations covered the area from the Corps of Engineers baseline seaward to a point 3,500 feet offshore. The results are shown on Figure 7.29 in the form of cumulative volume change curves for the area from Beaufort Inlet to station 100+00 (Fort Macon) and from station 100+00 to 290+00 (Atlantic Beach). The 1991 peak in the cumulative curve for the section from station 100+00 to 290+00 was due to the 1986 Brandt Island pump-out. Interestingly, the 1994 disposal operation did not seem to affect the cumulative volume change curve between the July 1991 survey and the November 2000 survey as the section of the beach between 100+00 and 290+00 eroded at a rate of 695,000 cubic yards/years. For the entire period between 1958 and 2001, the Fort Macon section eroded at a rate of 116,000 cubic yards/year while the Atlantic Beach segment lost material at a rate of 75,000 cubic yards/year. These volumetric losses occurred in spite of the disposal of over 6.9 million cubic yards of beach compatible

Figure 7.21 Bogue Banks Station 50+00
January 1958, October 1972, September 1981, July 1991, & November 2000
Station 53+02, April 2001



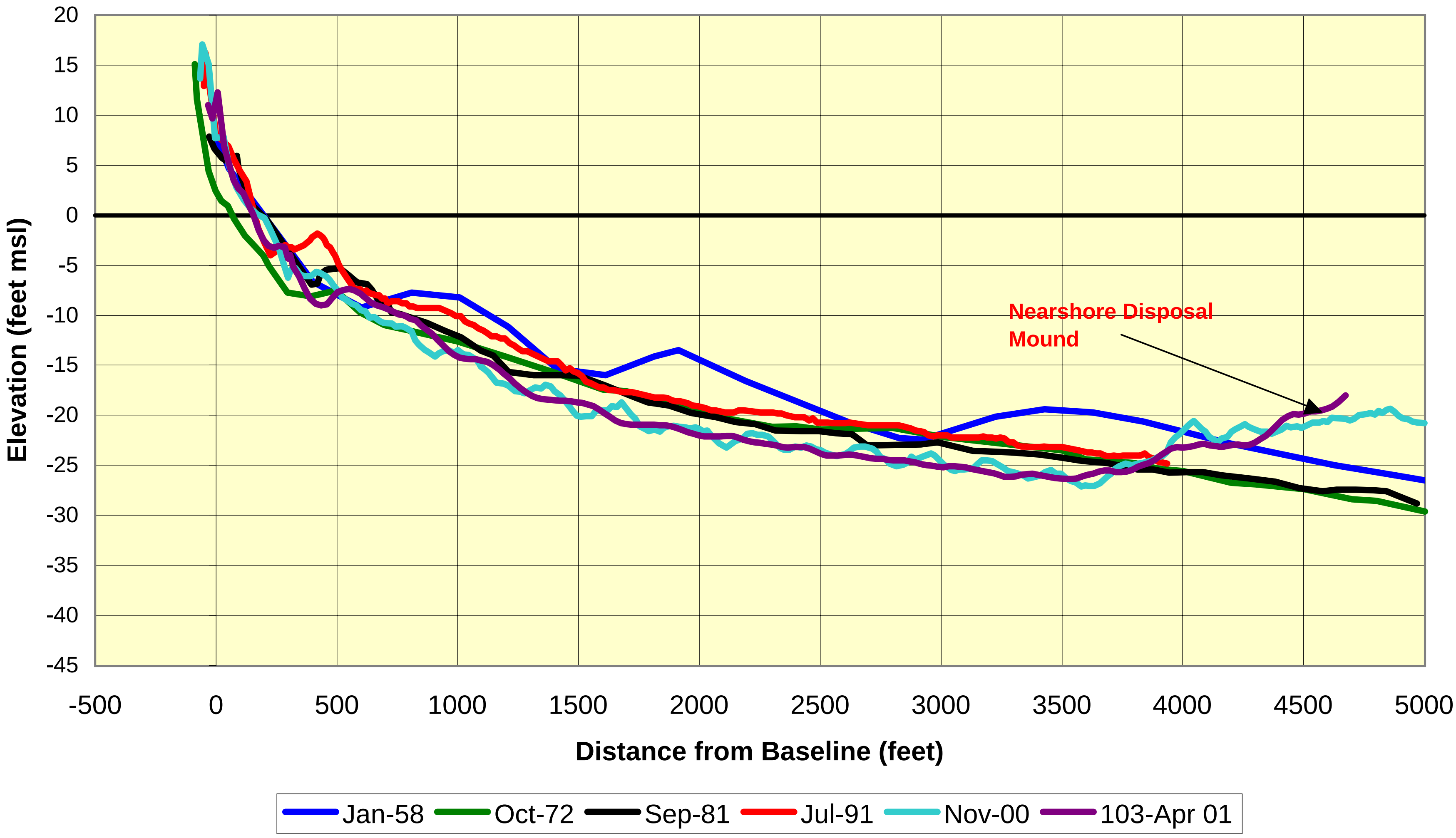
33 to 210.xls
50

Figure 7.22 Bogue Banks Station 70+00
January 1958, October 1972, September 1981, July 1991, & November 2000
Station 73+07, April 2001



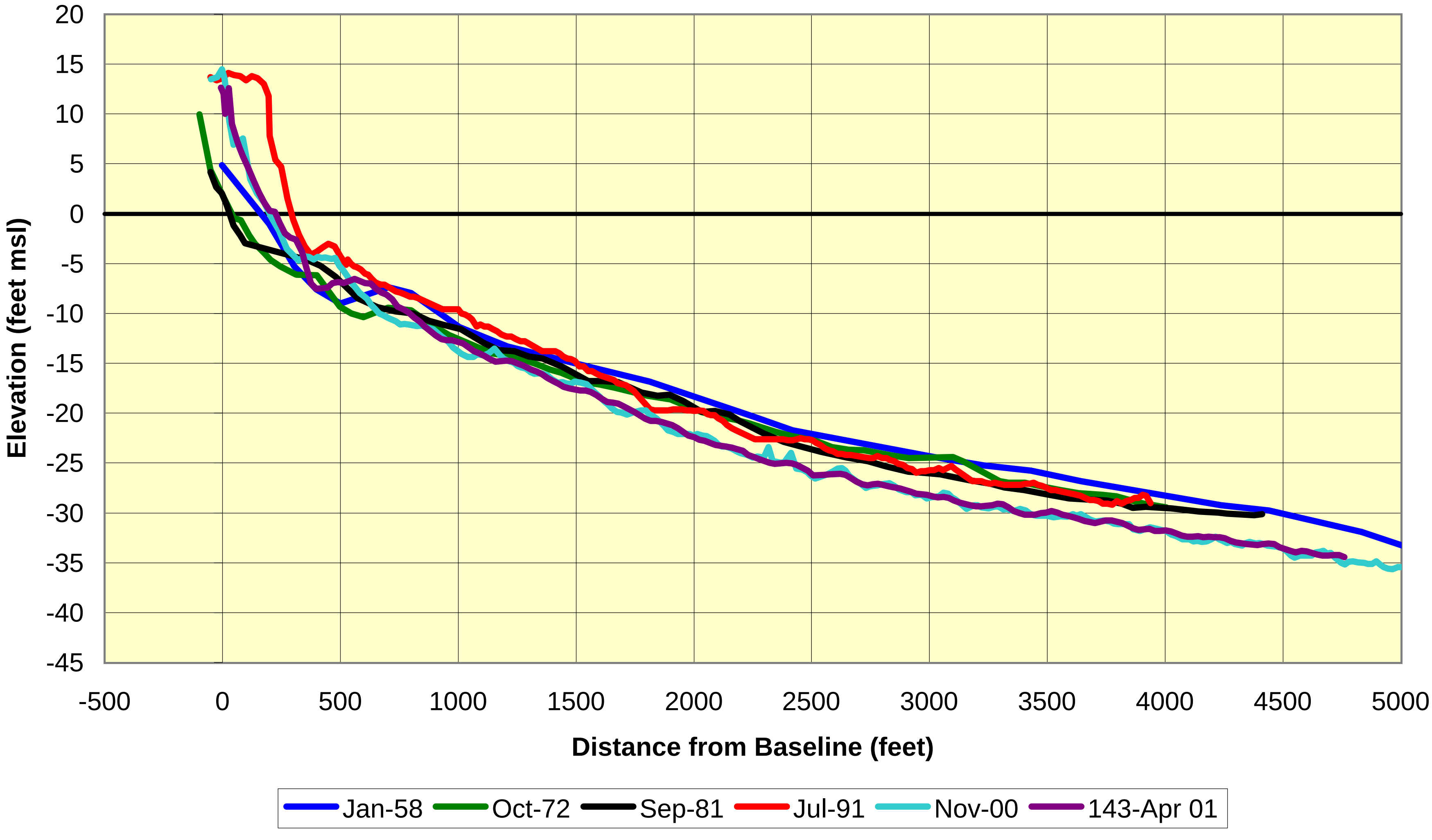
33 to 210.xls
70

Figure 7.23 Bogue Banks Station 100+00
January 1958, October 1972, September 1981, July 1991, & November 2000
Station 103+44, April 2001



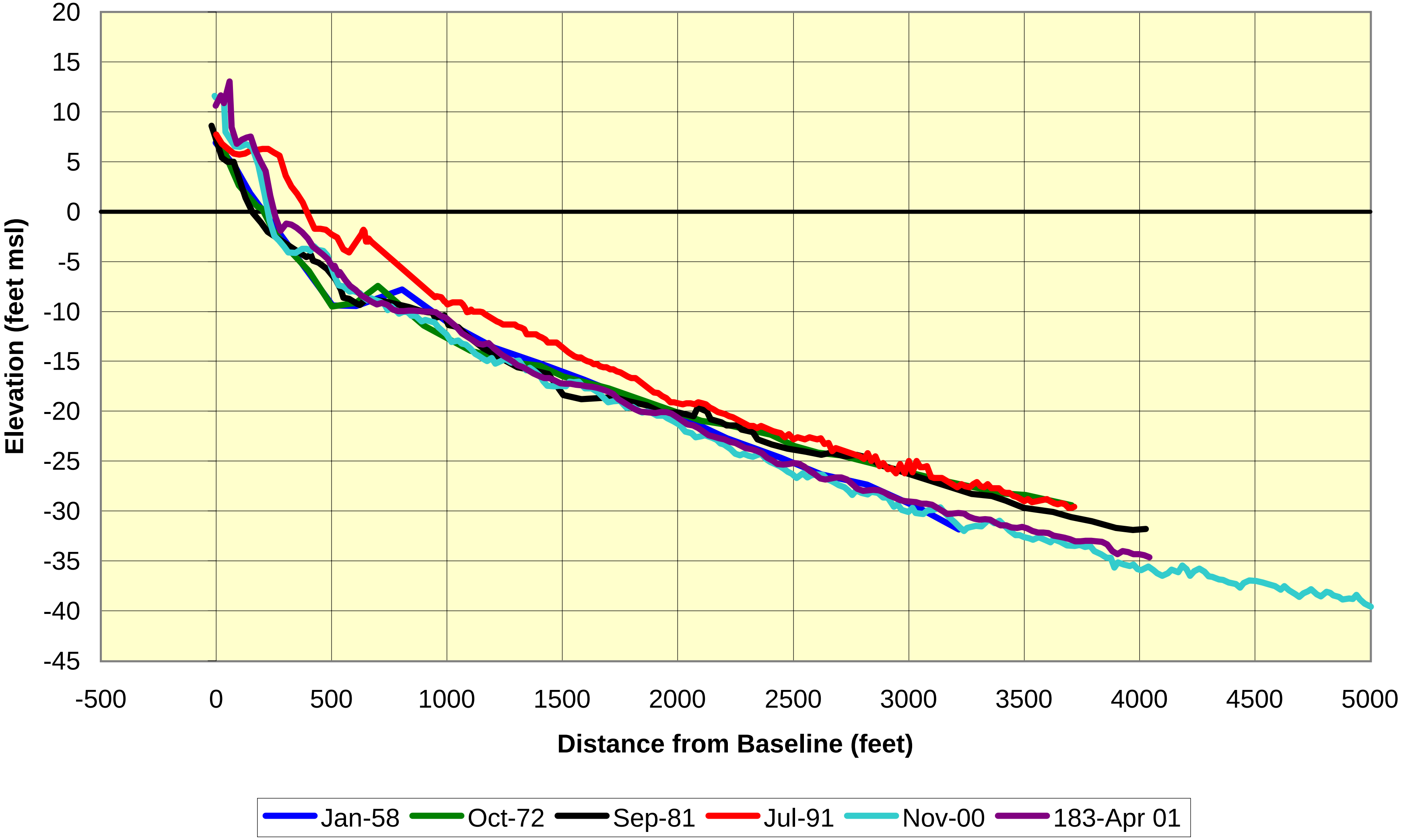
33 to 210.xls
100

Figure 7.24 Bogue Banks Station 140+00
January 1958, October 1972, September 1981, July 1991, & November 2000
Station 143+37, April 2001



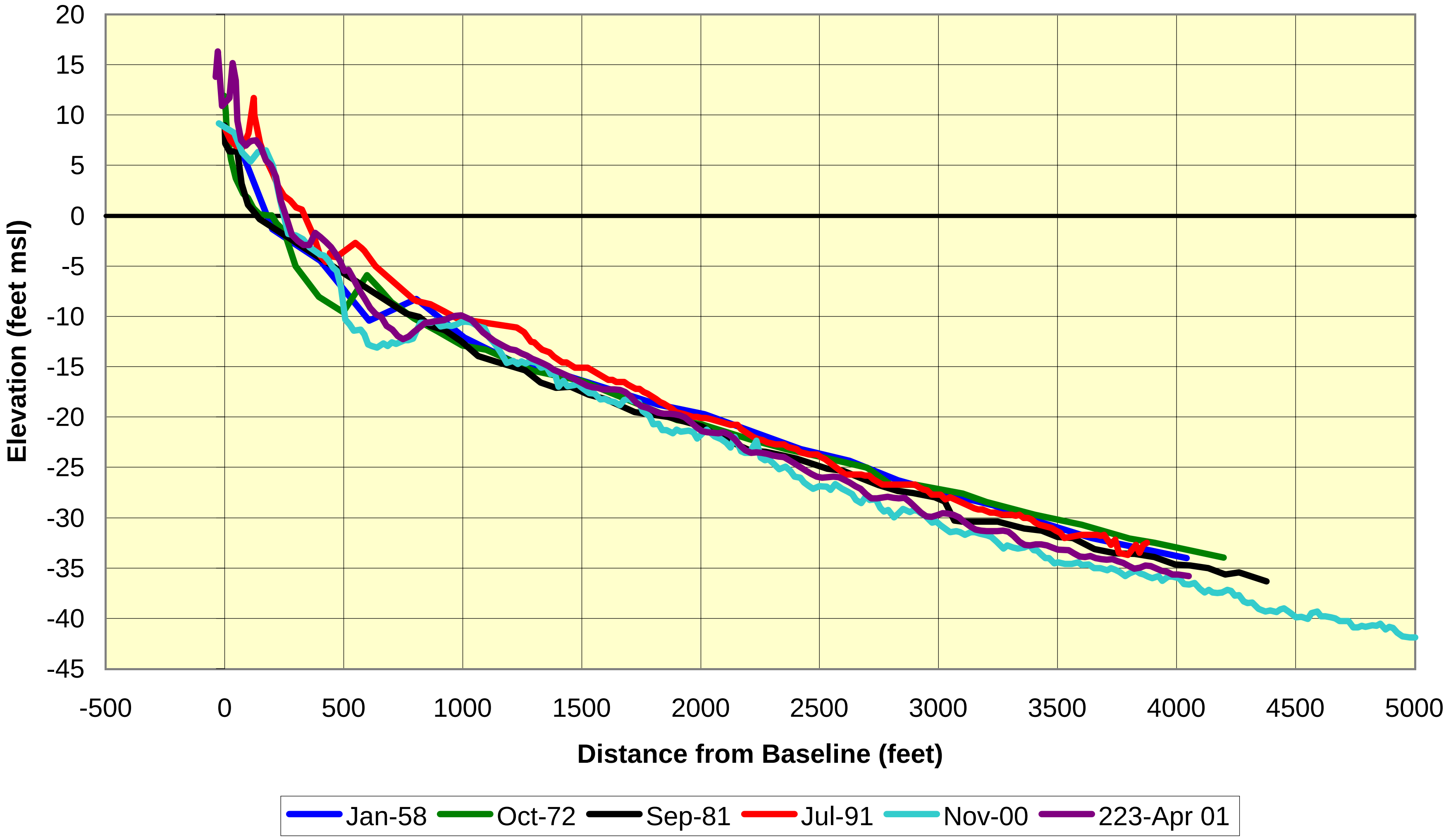
33 to 210.xls
140

Figure 7.25 Bogue Banks Station 181+00
January 1958, October 1972, September 1981, July 1991, & November 2000
Station 183+37, April 2001

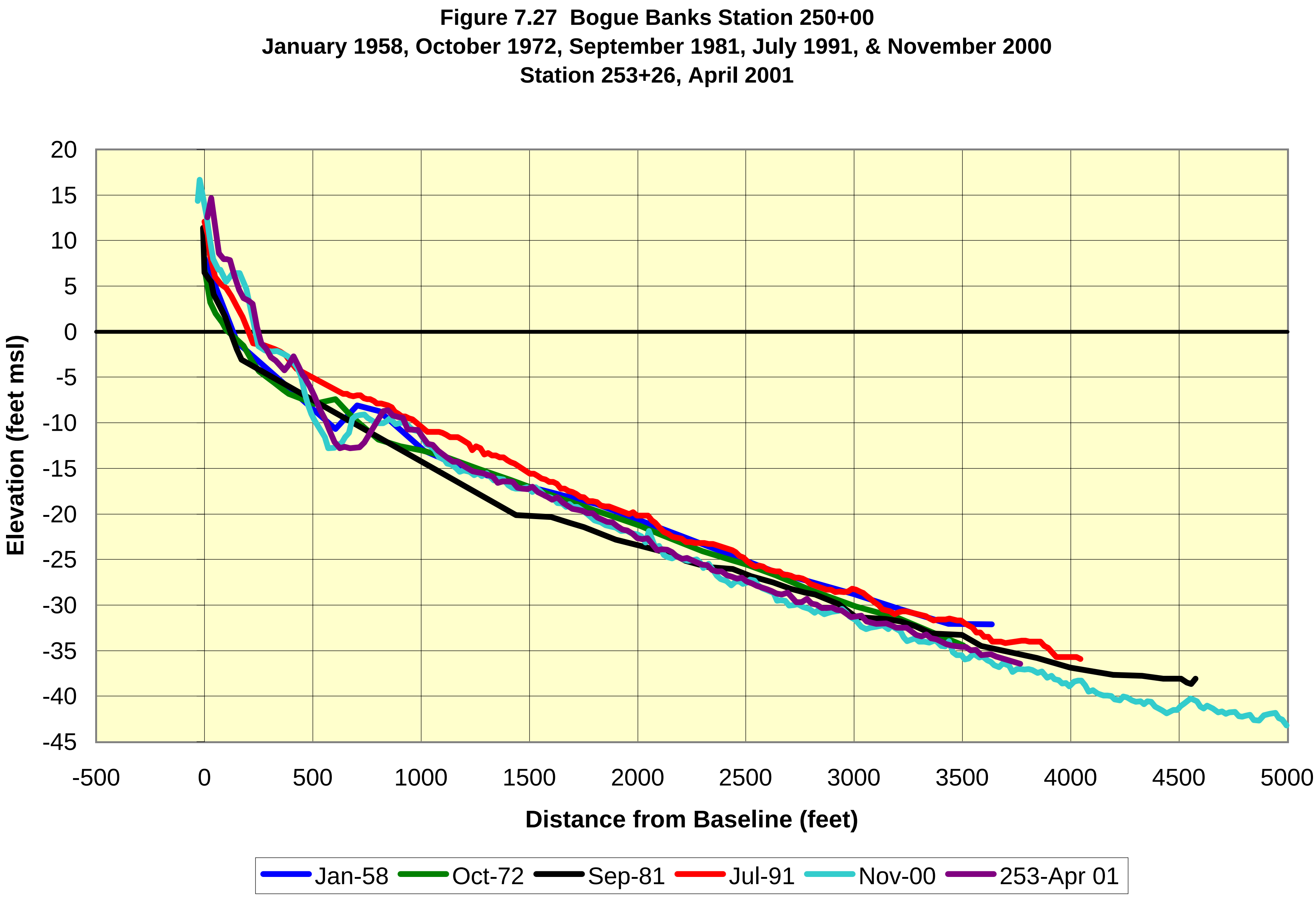


33 to 210.xls
181

Figure 7.26 Bogue Banks Station 219+00
January 1958, October 1972, September 1981, July 1991, & November 2000
Station 223+28, April 2001

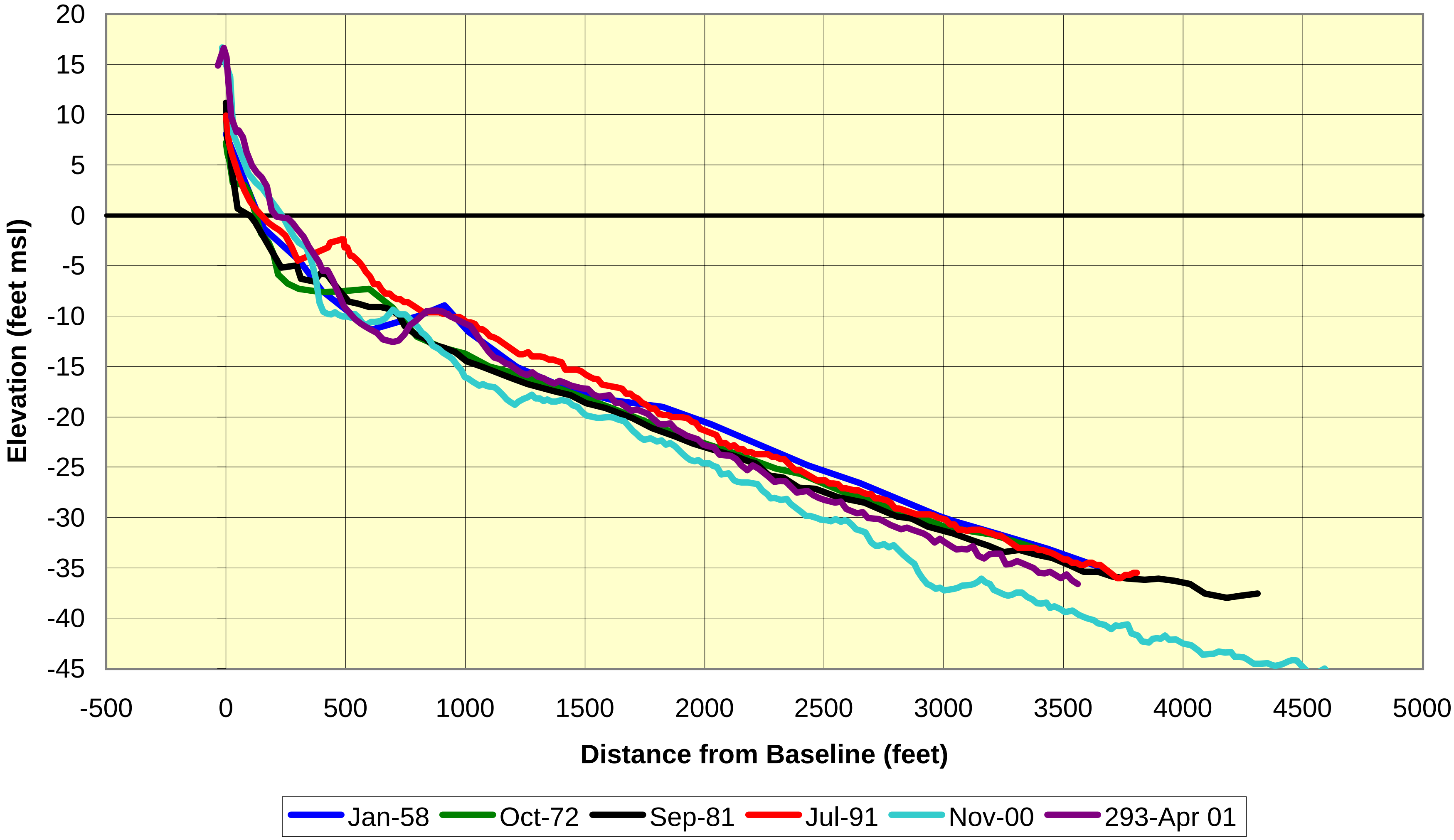


220 to 342.xls
219



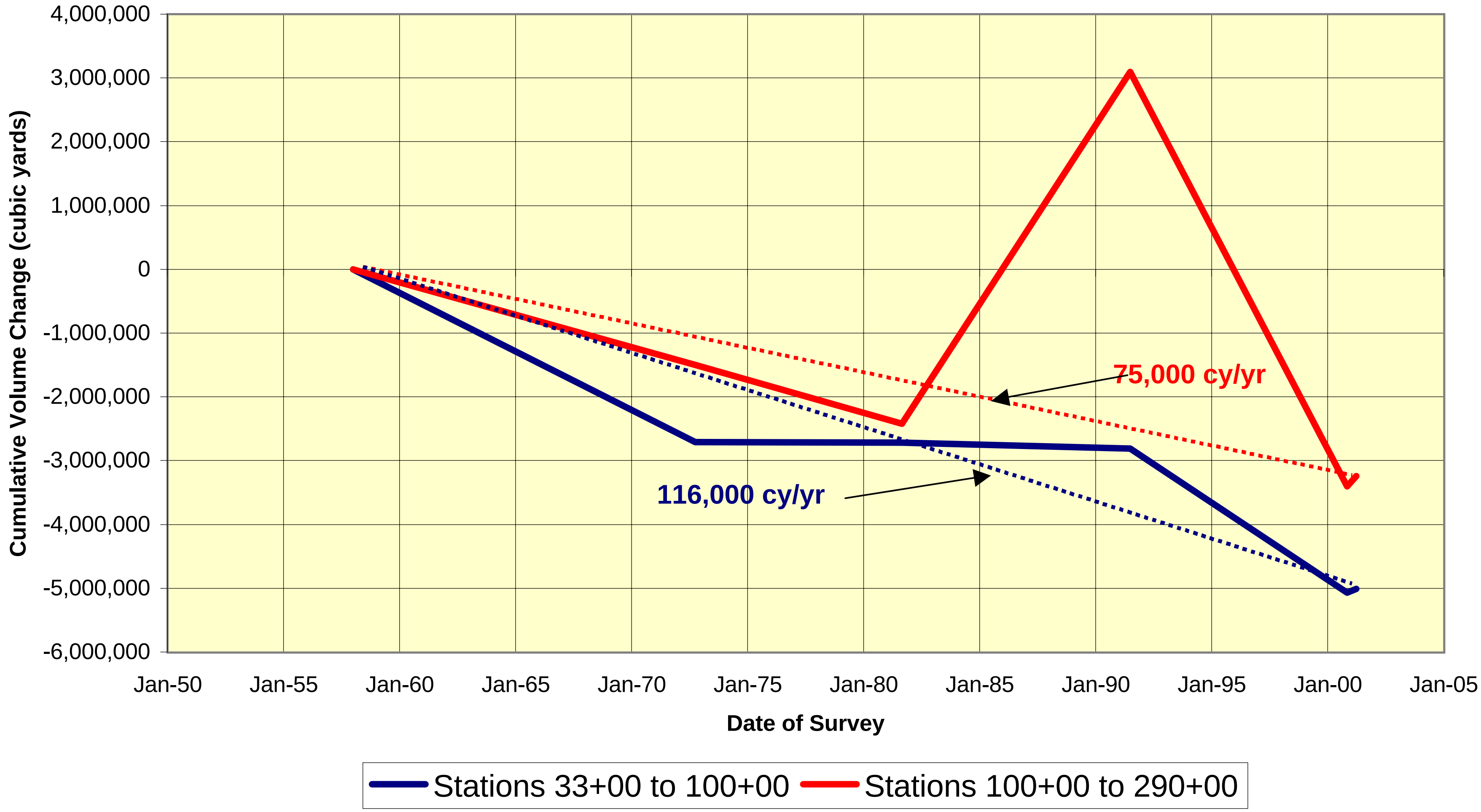
220 to 342.xls
250

Figure 7.28 Bogue Banks Station 290+00
October 1972, September 1981, July 1991, & November 2000
Station 293+26, April 2001



220 to 342.xls
290

Figure 7.29 Atlantic Beach and Fort Macon Cumulative Volume Change versus time (January 1958 to April 2001)



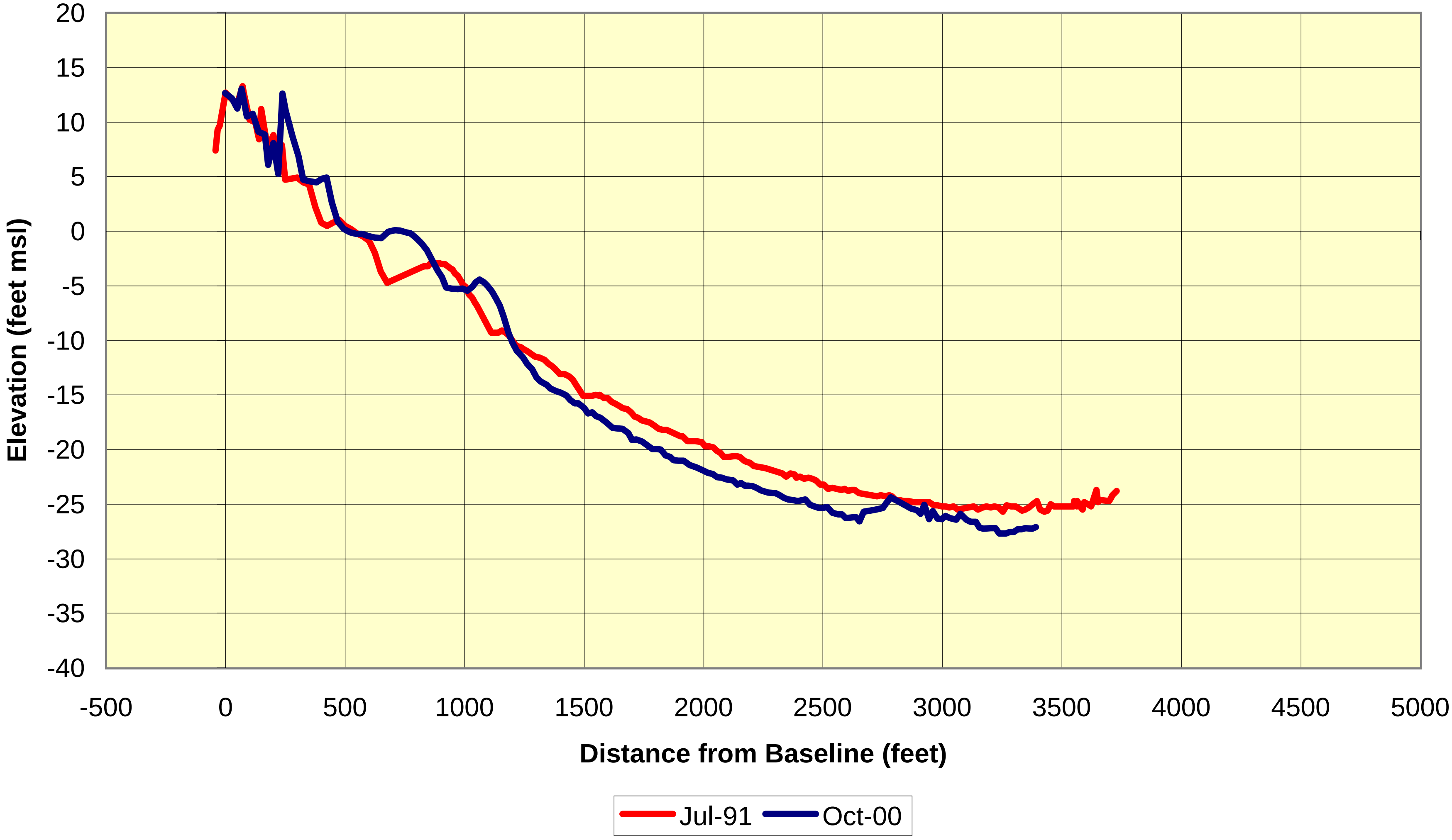
58to91bb.xls
plot cum vol vs time

material during the time period. The relatively large volumetric losses out to 3,500 feet offshore were not reflected in changes on the upper part of the beach as the ocean shoreline accreted in both of these areas during the 1958 to 2001 time period. Therefore, most of the volume loss from the Fort Macon and Atlantic Beach area was due to a deepening of the offshore profiles. The greatest amount of deepening occurred to the profiles located closest to Beaufort Inlet (stations 50+00 to 140+00) where the average increase in depth ranged from 7.2 feet to 2.2 feet. Average depth increases for the other profiles (181+00 to 290+00) were of the order of 1.0 to 1.5 feet.

7.37. Changes in the offshore bottom on the east end of Bogue Banks demonstrate that the Beaufort Inlet ebb tide delta acts as a control over the offshore depths west of the inlet. As the ebb tide delta of Beaufort Inlet has deflated or increased in depth, the offshore depths west of the inlet have also increased. The influence of the ebb tide delta deflation extends at least to station 290+00 and perhaps beyond. While the 1958 offshore profile survey did not extend beyond station 290+00, the July 1991, November 2000, and April 2001 surveys did. Comparison of the profile changes at these three station since 1991 showed that the profiles deepen by an average of from 1.0 to 1.6 feet.

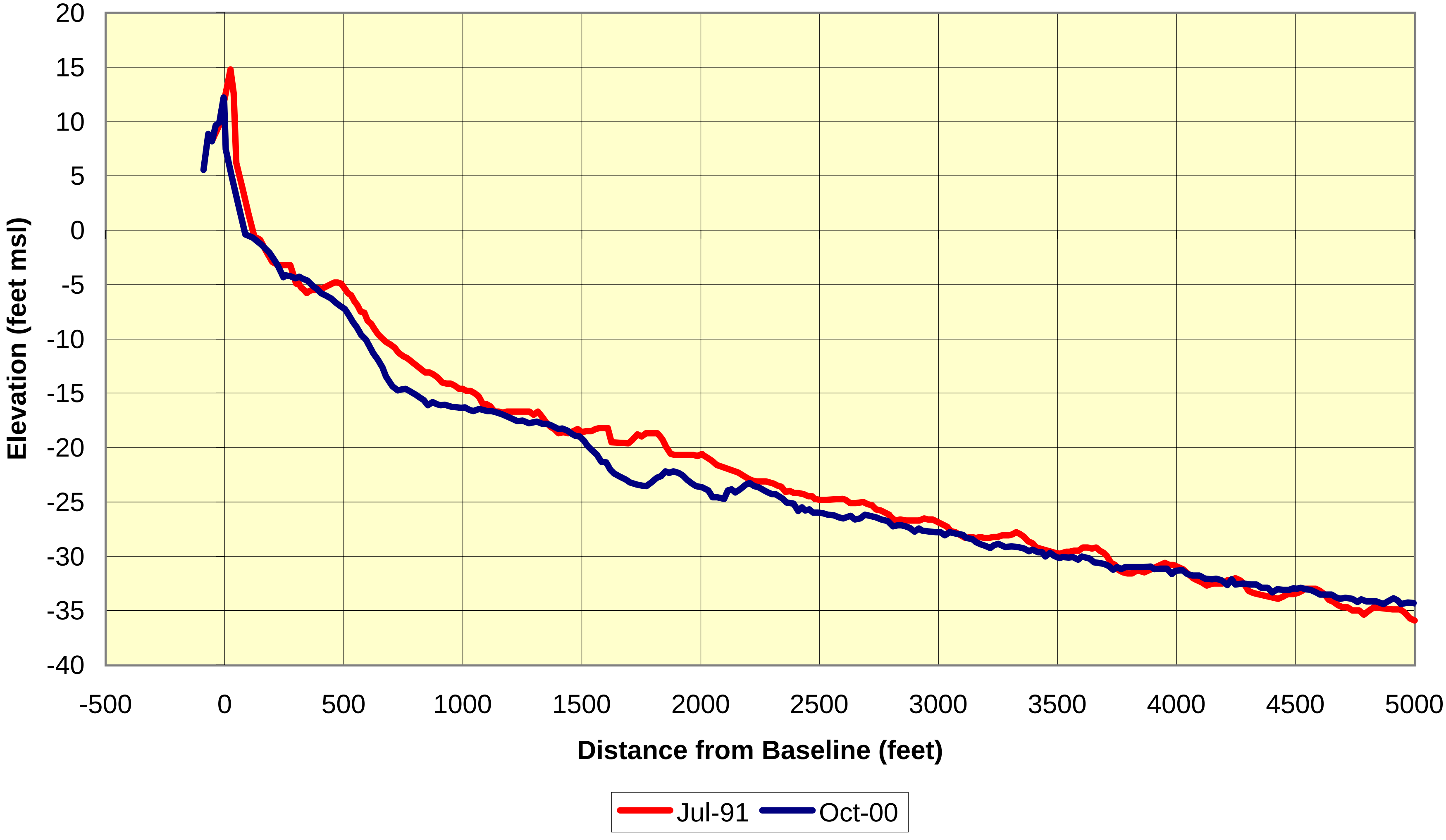
7.38. Offshore Changes-Shackleford Banks. Offshore profiles were taken in July 1991 and November 2000 along the entire length of Shackleford Banks. The spacing of the profiles ranges from about 1,600 feet to 2,800 feet but most spacing are around 2,000 feet. Comparative plots of selective profiles are shown on Figures 7.30 to 7.40. The general locations of the profile stations are shown on Figure 1.2. Station 40+80 is located on the east end of the island opposite the distal end of the recurved sand spit of Cape Lookout while stations 363+54 to 423+86 project across a portion of the ebb tide delta of Beaufort Inlet. The average annual rate of volume change was computed between each profile station and a cumulative plot of the volume change from Beaufort Inlet to Barden Inlet developed which is shown on Figure 7.41. Like the east end of Bogue Banks, the offshore portion of Shackleford Banks is getting deeper. The average depth increase for all of the profiles was 1.6 feet with the deepening being rather consistent from Beaufort Inlet to Barden Inlet. In the area from about station 300+00 to Beaufort Inlet, the volumetric erosion rate between July 1991 and November 2000 was -288,900 cubic yards/year. Along the middle of the island between stations 100+00 and 300+00, the volumetric erosion rate was -474,300 cubic yards/year and along the east portion of the island between station 10+00 and 100+00, the rate of volume loss was -143,000 cubic yards/year. Overall, the rate of volume loss from one end of the island to the other was rather uniform as indicated by the relatively straight cumulative volume change curve on Figure 7.41. As was the case for the east end of Bogue Banks, the volume changes determined from the offshore profiles do not match the trends observed for the shorelines. The shoreline trends showed the east end and west end of the island to be accreting and the middle portion of the island to be eroding, however, the offshore data shows erosion along the entire length of Shackleford Banks. Stations 363+54, 405+26, and 423+86, which project across the ebb tide delta of Beaufort Inlet, show that the ebb tide delta on the Shackleford Banks side of the inlet is also continuing to deepen or deflate. The amount of deepening of the ebb tide delta on the Shackleford Banks side has not been as great as that which has occurred on the Bogue Banks side. Between July 1991 and April

Figure 7.30 Shackleford Banks Station 40+80
July 1991 & October 2000



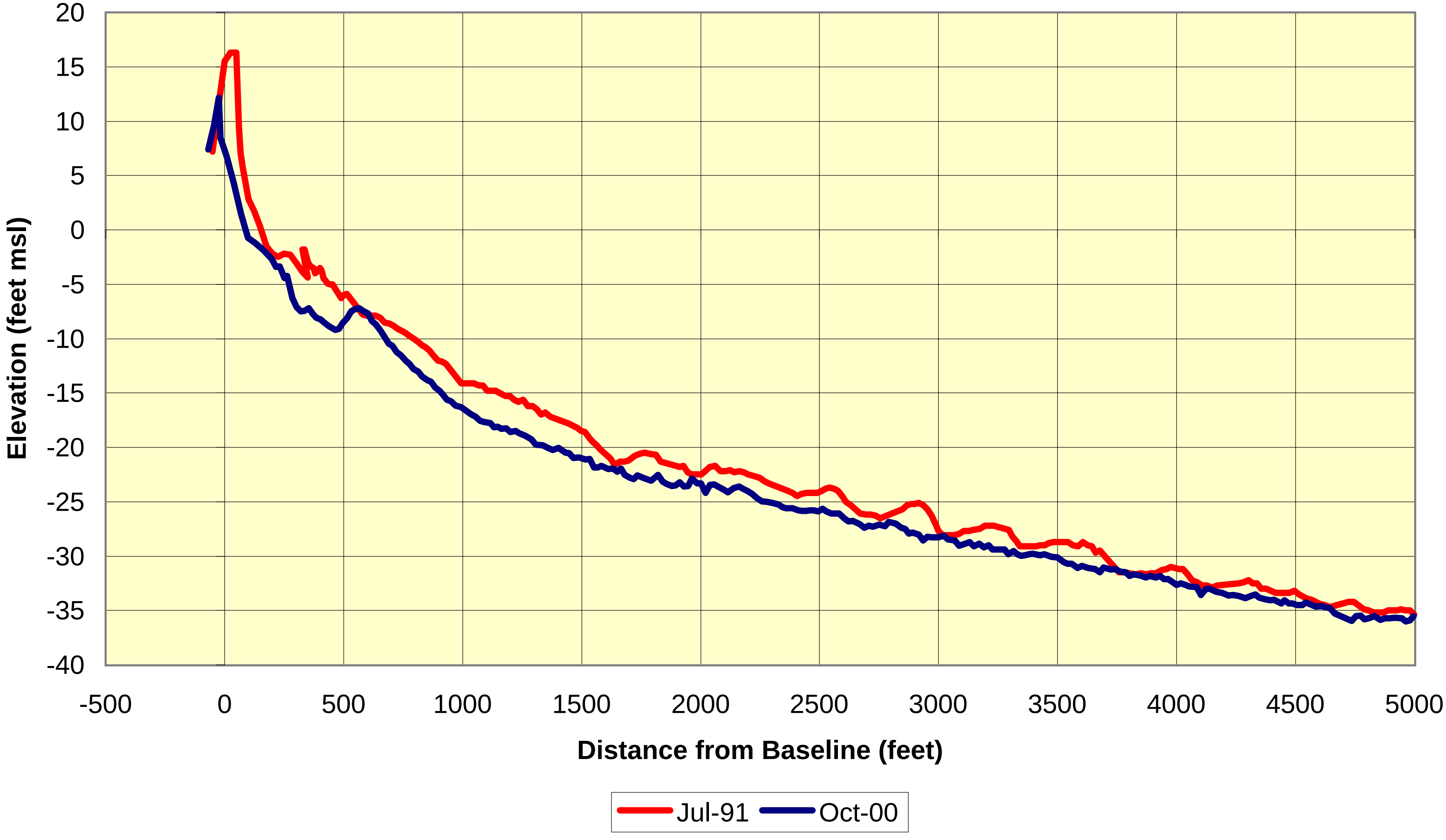
SB Oct 2000
40+80

Figure 7.31 Shackleford Banks Station 77+99
July 1991 & October 2000



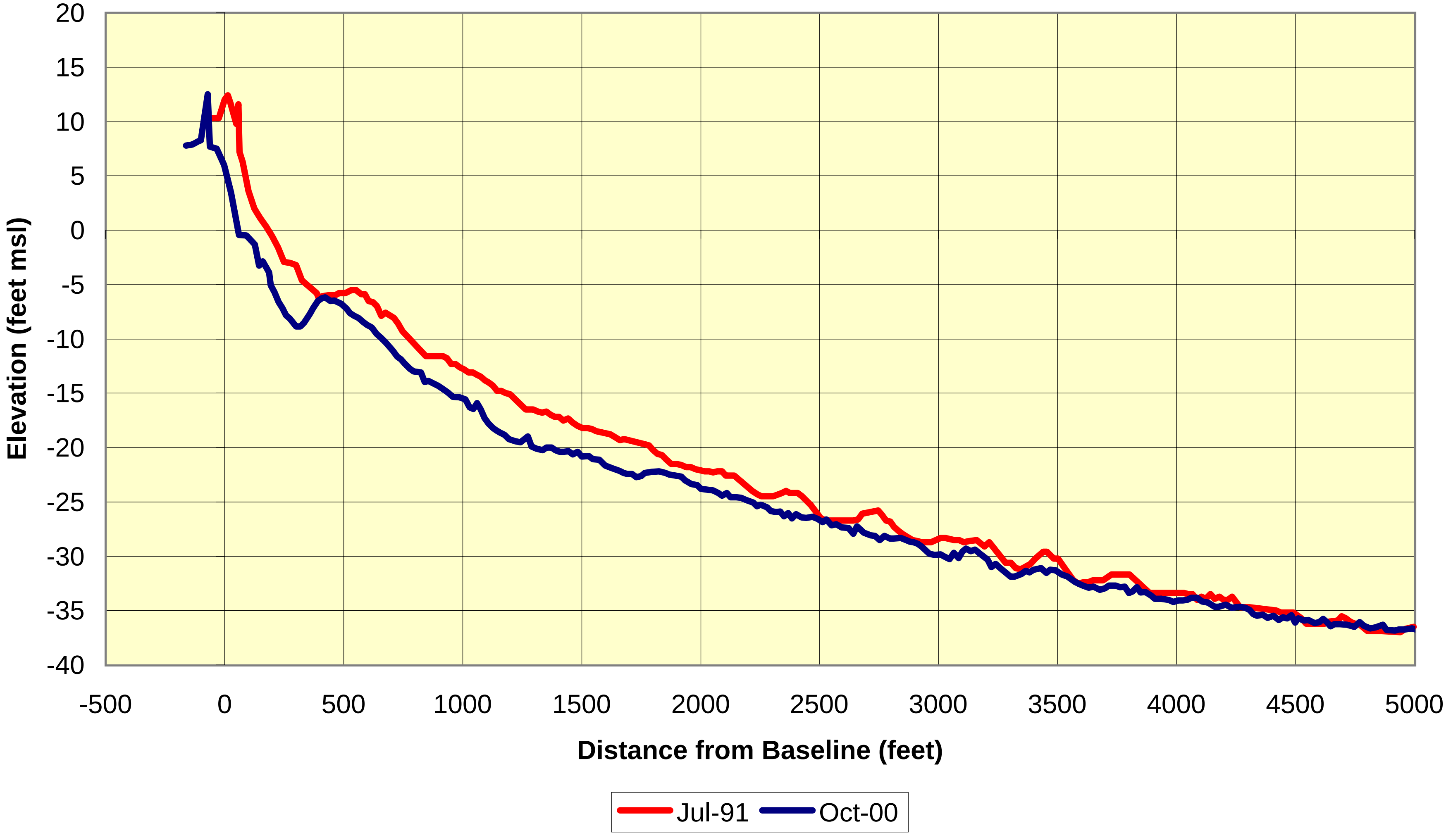
SB Oct 2000
77+99

Figure 7.32 Shackleford Banks Station 113+29
July 1991 & October 2000



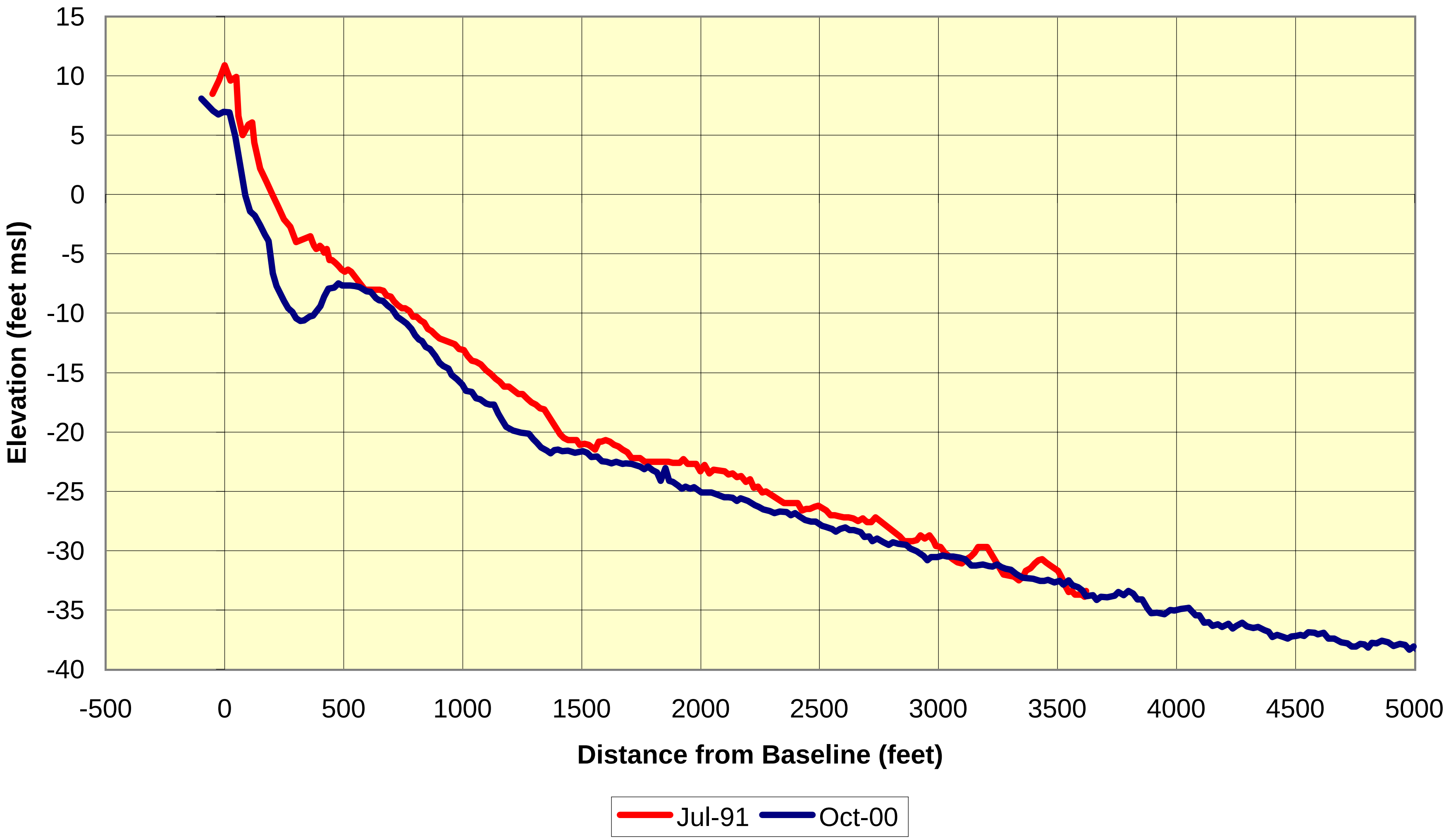
SB Oct 2000
113+29

Figure 7.33 Shackleford Banks Station 152+46
July 1991 & October 2000



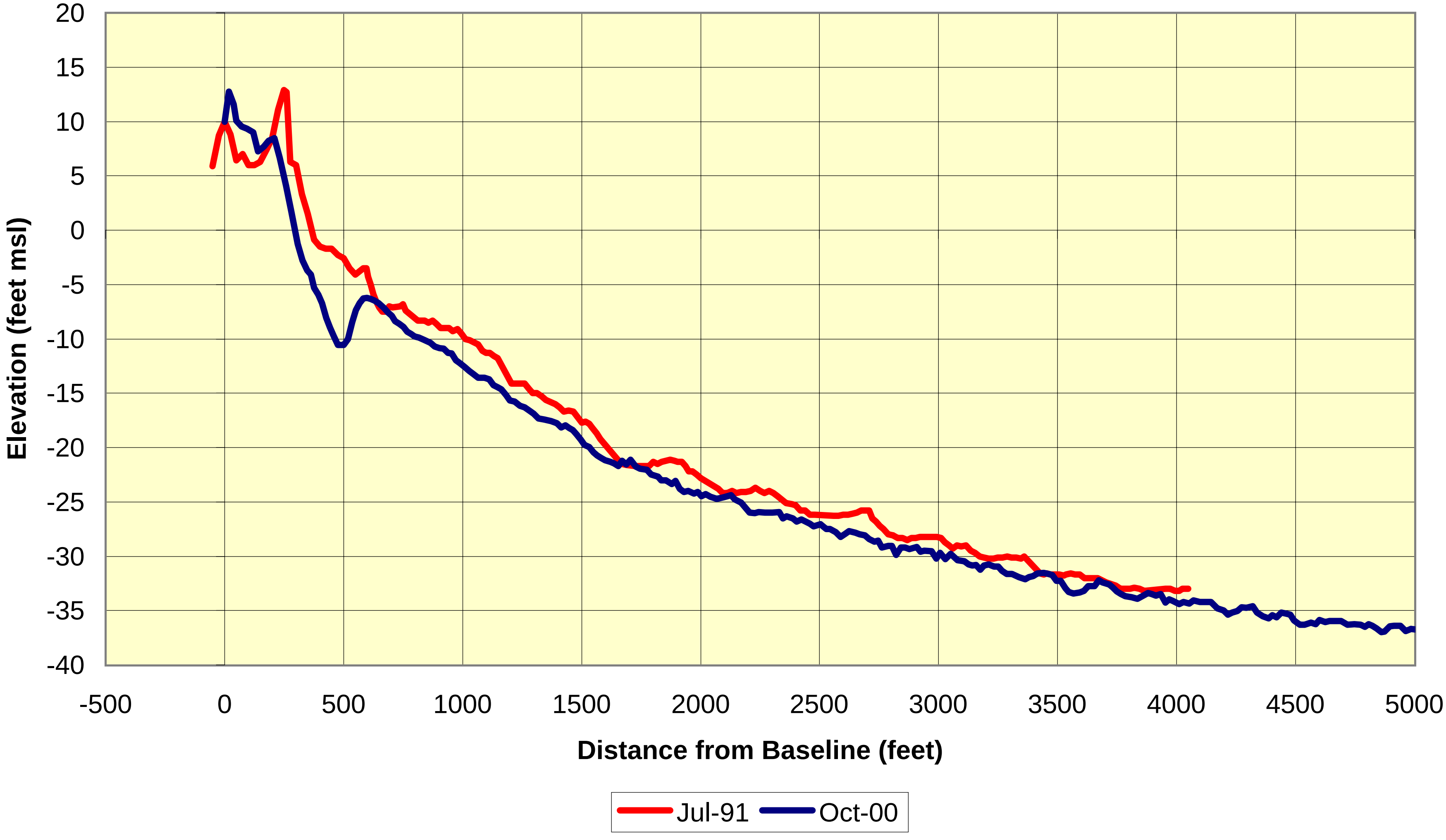
SB Oct 2000
152+46

Figure 7.34 Shackleford Banks Station 190+44
July 1991 & October 2000



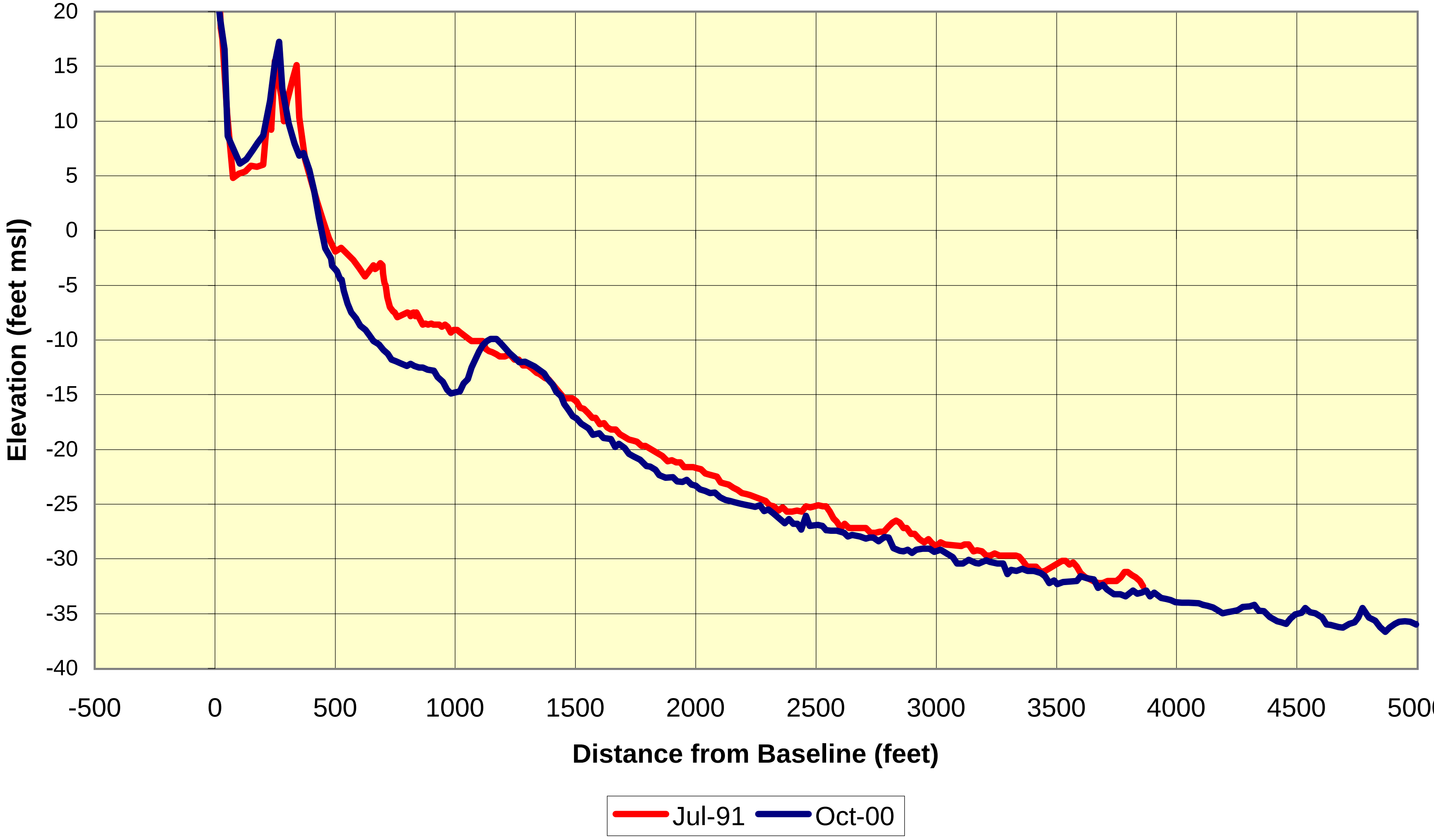
SB Oct 2000
190+44

Figure 7.35 Shackleford Banks Station 229+22
July 1991 & October 2000



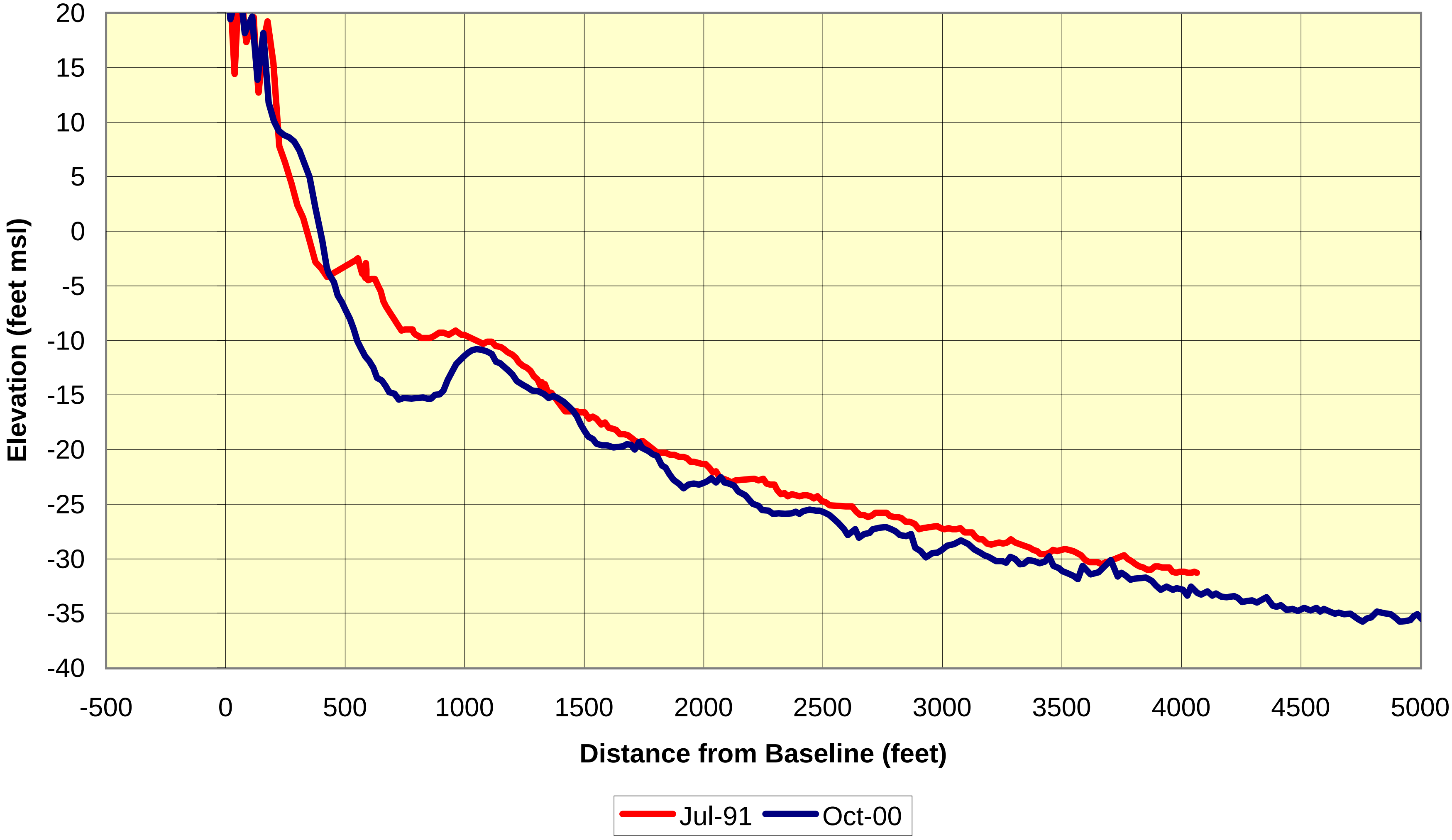
SB Oct 2000
229+22

Figure 7.36 Shackleford Banks Station 272+15
July 1991 & October 2000



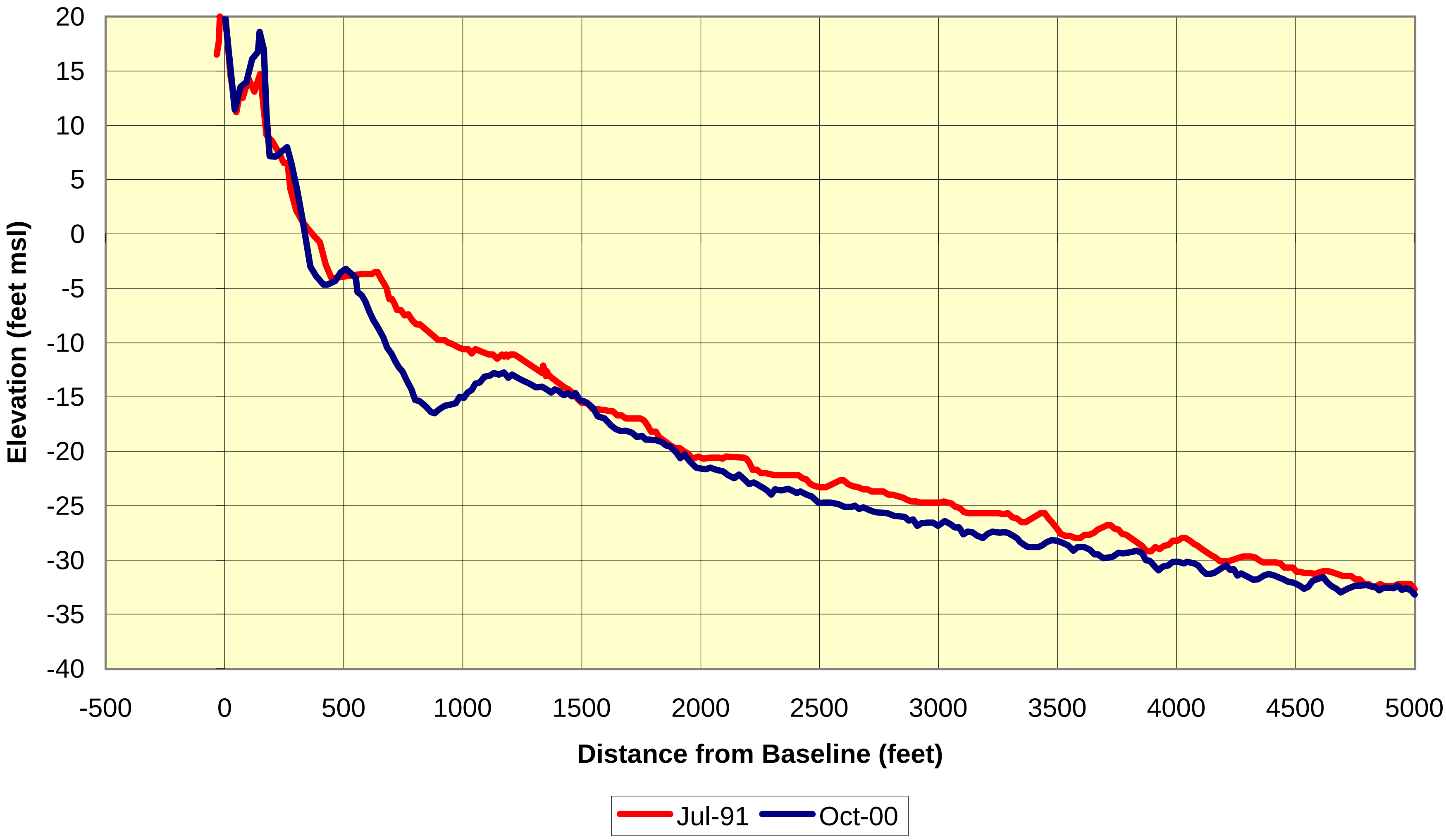
SB Oct 2000
272+15

Figure 7.37 Shackleford Banks Station 322+18
July 1991 & October 2000



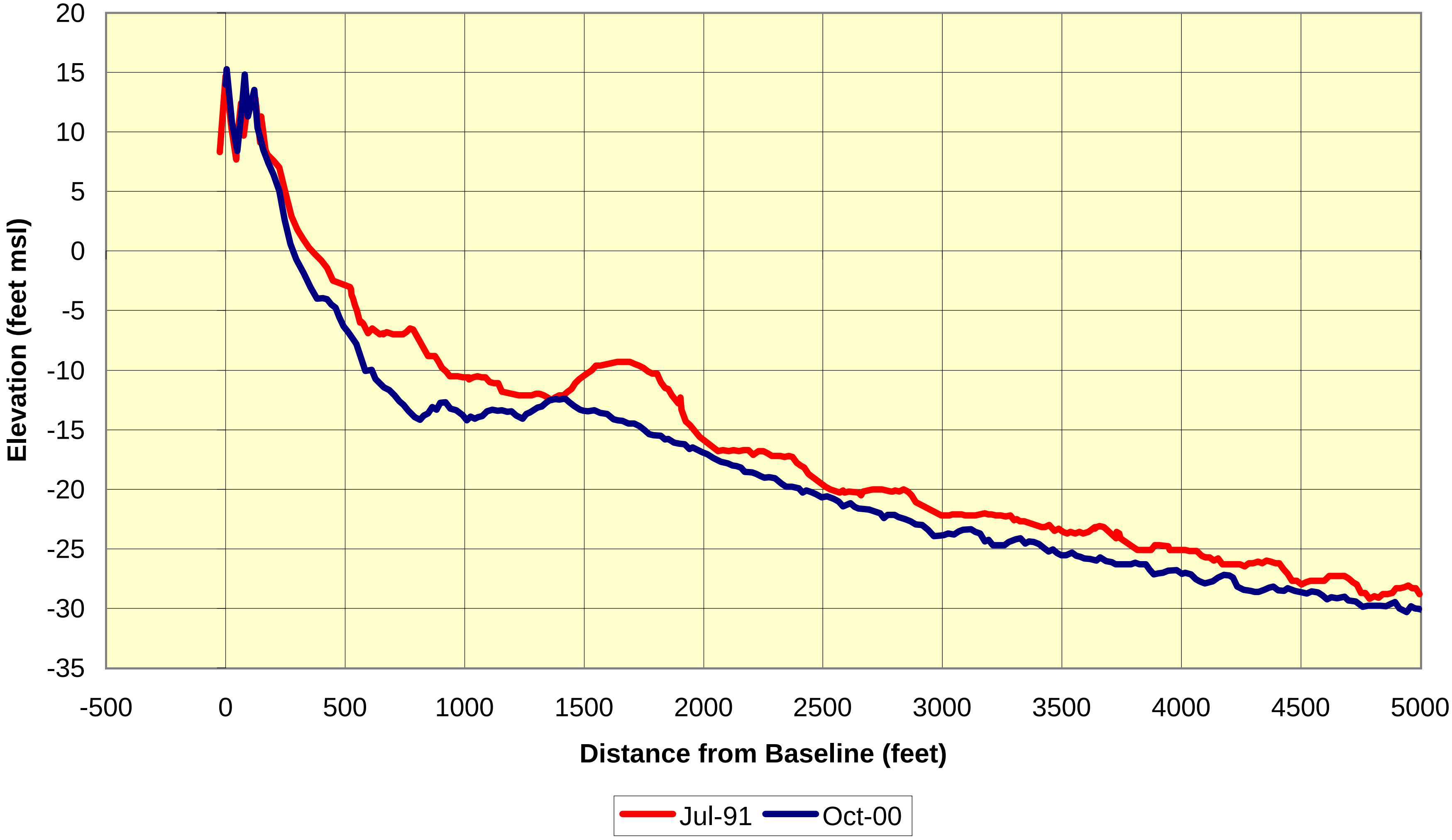
SB Oct 2000
322+18

Figure 7.38 Shackleford Banks Station 363+54
July 1991 & October 2000



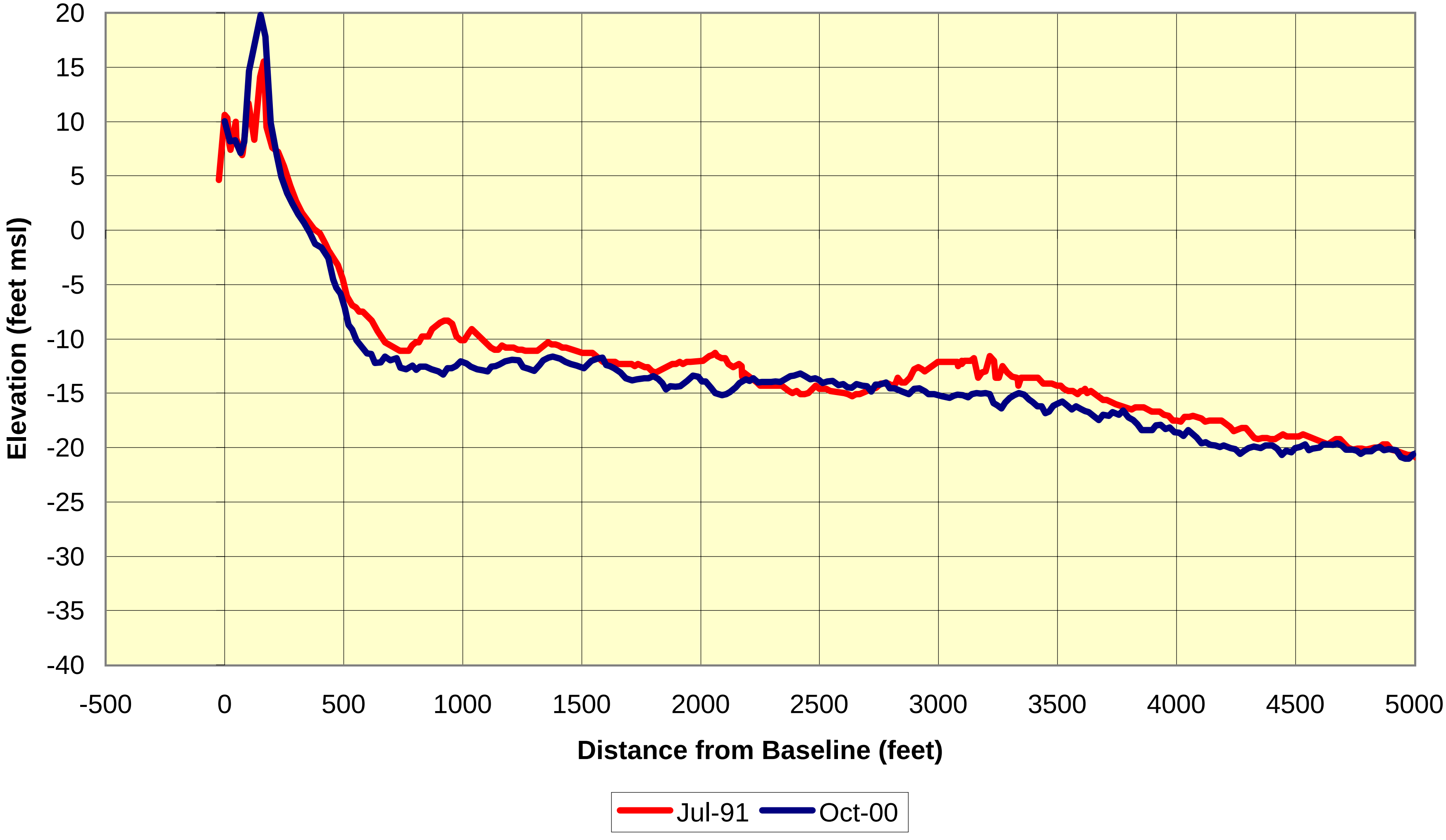
SB Oct 2000
363+54

Figure 7.39 Shackleford Banks Station 405+26
July 1991 & October 2000



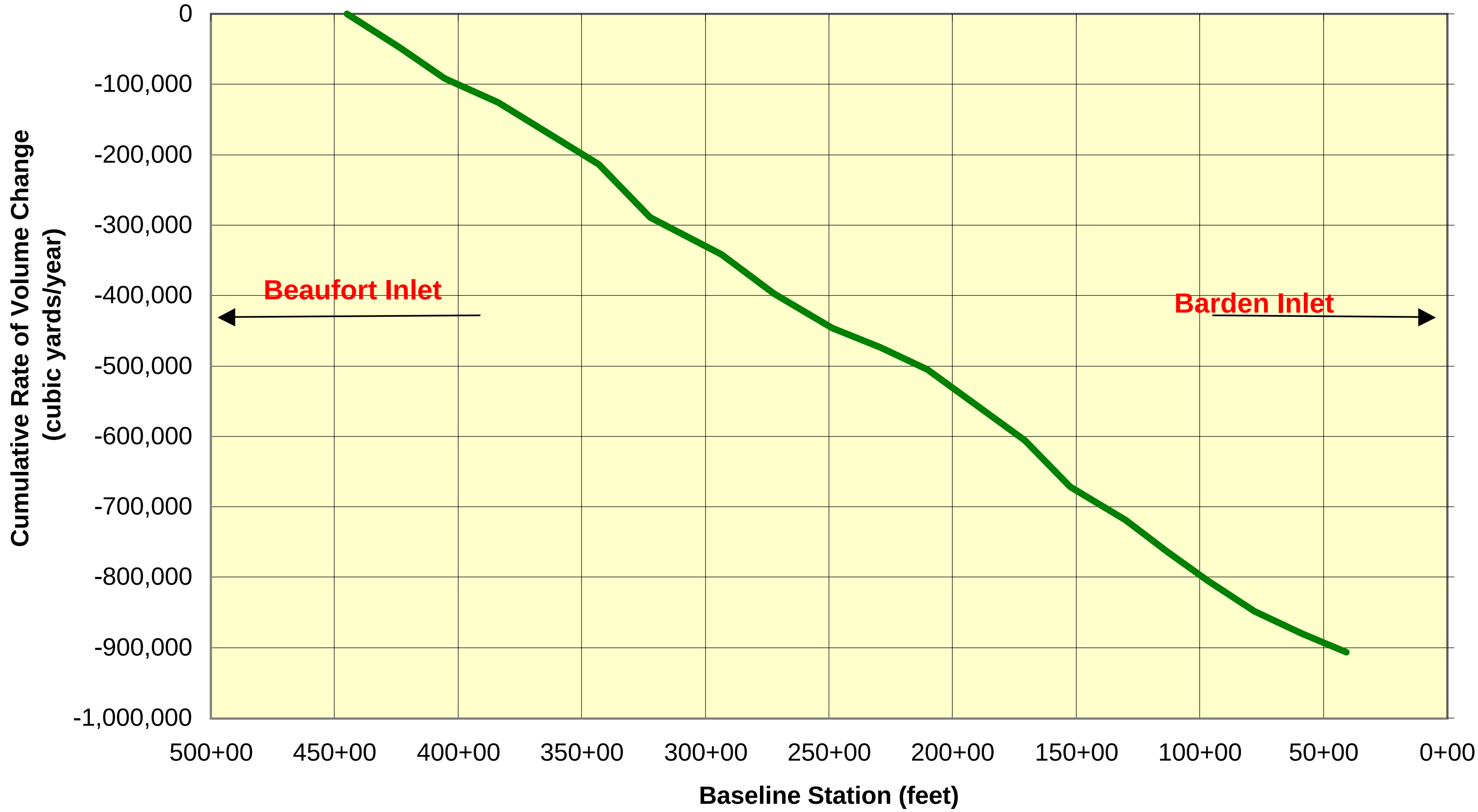
SB Oct 2000
405+26

Figure 7.40 Shackleford Banks Station 423+86
July 1991 & October 2000



SB Oct 2000
423+86

Figure 7.41 Shackleford Banks
Cumulative Annual Rate of Volume Change
July 1991 to October 2000
(from Beaufort Inlet to Barden Inlet)



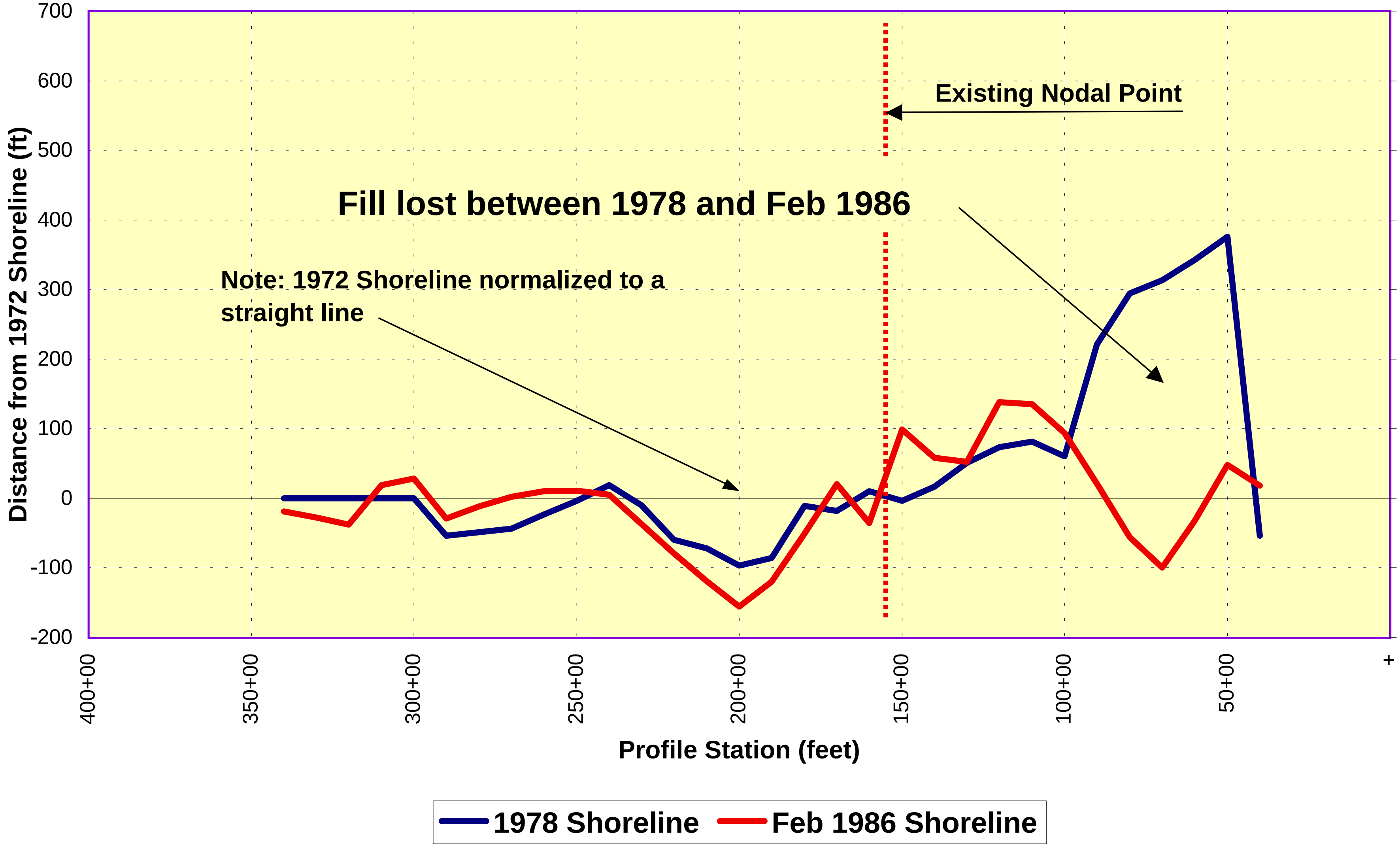
Shack SL 79 to 2000.xls
cumulative vol

2001, Bogue Banks profiles from station 33+00 to 150+00 deepened by an average of 2.8 feet whereas, between July 1991 and November 2000, stations 322+18 to 423+86 on Shackleford Banks deepen by an average of 1.5 feet. The greater amount of deepening on the Bogue Banks side versus the Shackleford Banks side appears to be consistent with a predominant sediment transport direction from east to west along the study area. Also, the deepening of the profiles off Shackleford Banks supports the conclusion that depths on the ebb tide delta of Beaufort Inlet have a significant if not controlling influence on the profile slopes of the two islands. The area of influence on the Bogue Banks side appears to be 6 to 7 miles, based on the diminishing amount of profile deepening in an east to west direction along the island. The limit of influence of the Beaufort Inlet ebb tide delta on Shackleford Banks is not as clear as depths off the entire island have increased a uniform amount. Depths off Shackleford Banks are not only controlled by the Beaufort Inlet ebb tide delta but are also influenced by the ebb tide delta of Barden Inlet and depth in the Cape Lookout Bight area. Historic bottom changes in these areas are unknown.

7.39. The different trends observed between the shorelines and the volume changes determined from the offshore profile data obviates the use of a standard tool used by many coastal engineers to convert shoreline changes to volume changes over the active profile. The engineering tool assumes that the entire active profile moves at the same rate as the shoreline. For example, if the active beach profile extended from the top of the normal beach berm, say elevation +6.0 feet msl, down to a closure depth of –30.0 feet msl, the active beach profile would have a total vertical height of 36 feet. If the shoreline changed by one foot, the entire 36 feet would be assumed to move one foot. Therefore, the one-foot change in the shoreline position would be equivalent to 1.33 cubic yards per foot of shoreline *(=36feet/27 cubic feet/cubic yard)*. Obviously, this general “rule of thumb” cannot be applied to the shoreline change data developed for Bogue Banks and Shackleford Banks.

7.40. Evaluation of Fill Performance. A beach profile-monitoring program was initiated in 1978 following the deepening of the Morehead City Harbor project to 40-feet. Approximately 6.5 miles of Bogue Banks west of Beaufort Inlet is surveyed every year using profile spacing of about 1,000 feet. The profile data for Bogue Banks was used to evaluate the performance of the 1978, 1986, and 1994 beach fills created by the disposal of maintenance and new work material removed from the inner harbor. For this analysis, the position of the shoreline at various times was represented by the 0-foot msl contour. The profile data used in the analysis only covered the upper part of the beach from just landward of the Corps of Engineers baseline seaward to depths of –4 to –5 feet msl. Therefore, volumetric changes, including the volume of material deposited along various portion of the beach and the volume losses over time were prorated based on the changes in beach width (represented by the 0-foot msl contour). Given the differences observed in the shoreline behavior and the offshore volume changes, discussed above, the prorating of fill volumes based on shoreline widths and change in shoreline widths is subject to considerable error. However, this procedure is believed to provide a reasonable estimate of the volumetric changes that occurred along various fill sections.

Figure 7.42 Bogue Banks Shoreline Changes 1972 to Feb 1986
Losses from 1978 fill



BBSHRLN
72 TO 2-86

7.41. 1978 Disposal. A total of 1,179,700 cubic yards of material was pumped to the Fort Macon shoreline in 1978 during the construction of the 40-foot mlw project. Of this total, 69 percent, or 814,000 is estimated to have been beach quality material. The beach between baseline stations 40+00 and 100+00 was widened between 200 and 390 feet by this disposal operation as shown on Figure 7.42. In this figure, the 1978 shoreline position is shown relative to the 1972 shoreline, i.e., the 1972 shoreline was normalized to a straight line. This was done in order to show the deviation of the 1978 and subsequent shorelines from the 1972 alignment. The 1972 shoreline was judged to be the normal shoreline alignment for this section of Bogue Banks. By February 1986, or just prior to the 1986 beach disposal operation, all of the beach fill material had been eroded and the shoreline in some areas actually receded landward of the 1972 shoreline position. As can be seen on Figure 7.42, the east end and west ends of the fill had sharp transition angles, estimated to be 23 degrees on the east end and 11 degrees on the west. Also, all of the material was deposited east of the sediment transport nodal zone, i.e., the zone where the predominant direction of littoral transport changes from west to east. The existing nodal point on Bogue Banks is located near baseline station 151+00 as indicated on Figure 7.42. As a result of the inordinate transition angles, sediment transport out of the fill area increased dramatically. With the material being placed east of the nodal zone, most of the material appeared to be transported directly back into Beaufort Inlet as the 5,000 feet of beach west of the disposal area showed only minor accretion between 1978 and 1986.

7.42. Explanation of Losses due to Transition Angles. Littoral sediment transport is a function of the longshore component of wave energy flux (P_l) at the breaker line, which is approximated by:

$$P_{lb} = (\rho g/16)\, H_b^2\, C_b \sin 2\alpha_b$$

where: H_b = Height of the breaking wave
C_b = Wave speed at breaking
α_b = Wave breaker angle relative to the shoreline

If all of the components in the above equation are the same except for the breaker angle, the rate of sediment transport from one section of the beach to another becomes a function of the breaker angle. Along most sections of the southeast coast of North Carolina, waves break at an angle of between 6 and 10 degrees relative to the natural shoreline alignment. In the case of the 1978 Fort Macon fill, the angle of the east transition of the fill relative to the normal shoreline alignment was 23 degrees. Therefore, immediately following placement, sediment transport to the east along the east transition of the fill would have been increased by a factor equal to the sin of 2 times the breaker angle along the transition section divided by the sin of 2 times the breaker angle along a normal shoreline alignment. For this example, assume that the breaker angle is 8 degrees for a normal shoreline alignment. The resulting increase in potential transport to the east along the east transition of the 1978 fill for waves approaching from the southeast would be:

$$\text{Increased Transport} = \sin(2 \times (23^\circ + 8^\circ)) / \sin(2 \times (8^\circ)) = 10.4.$$

If the normal rate of sediment transport to the east in this area is 350,000 to 400,000 cubic yards/year (as indicated by Figure 7.6), the initial rate of sediment transport along the east transition immediately following the fill placement could have been equivalent to 3.5 to 4.0 million cubic yards/year. This inordinate rate of longshore transport would not have persisted for very long as the shoreline bulge created by the fill would have been rapidly eroded and the shoreline returned to a more natural alignment. Over time, as material was transported out of the fill area, the severity of the transition angle would have decreased, as would the rate of longshore transport. However, as indicated on Figure 7.42, by the time this occurred, essentially all of the 1978 fill material had been removed from the Fort Macon shoreline. The 11 degree transition angle on the west end of the 1978 fill would have also increased the potential sediment transport to the west by a factor of 5. However, the normal rate of transport to the west in this area is relatively small (see Figure 7.6) since it is east of the nodal point as indicated on Figure 7.42. As a result, very little material should have moved to the west, which is what the shoreline survey data indicated.

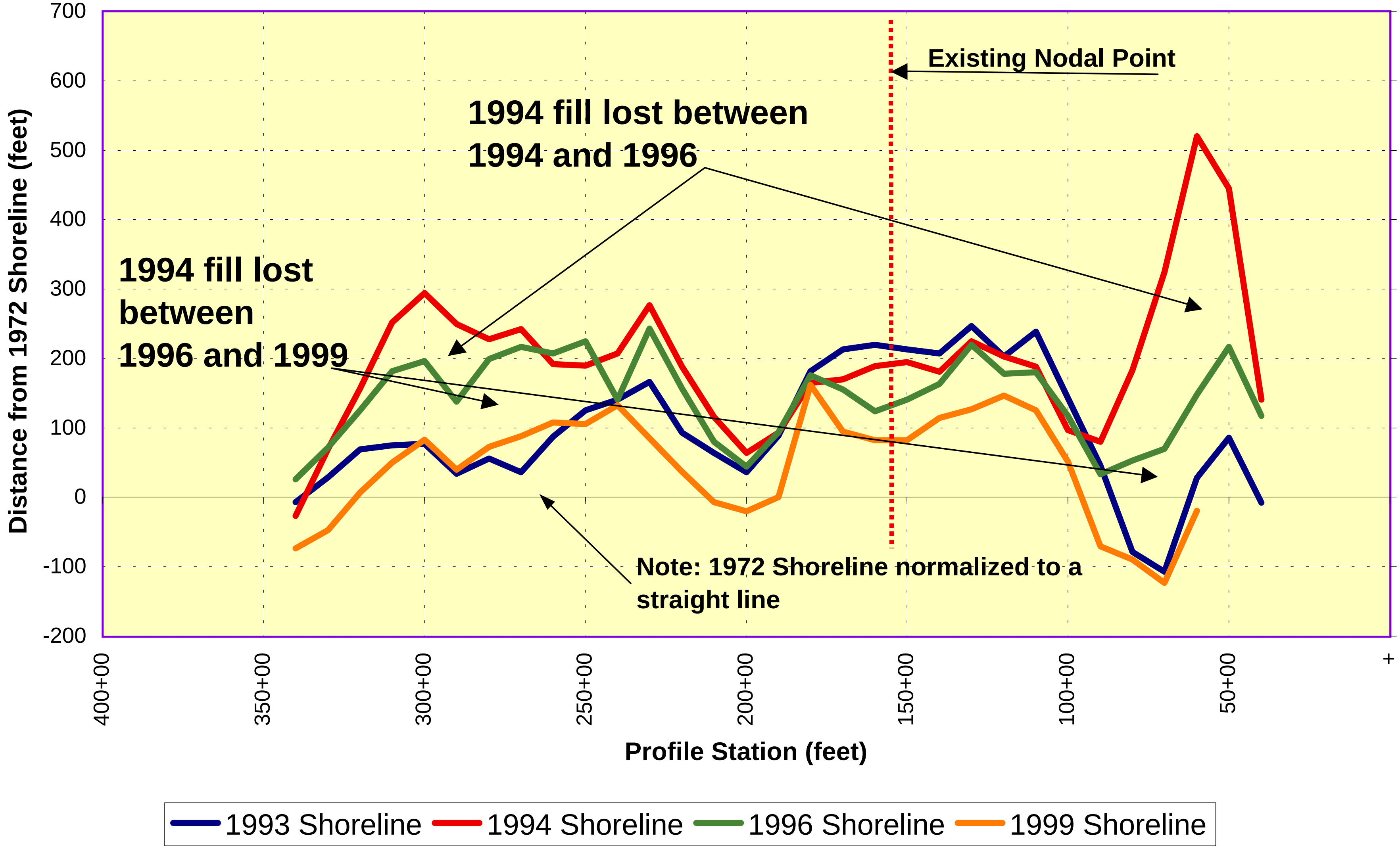
7.43. 1986 Disposal. A total of 4,167,600 cubic yards of material was pumped to Atlantic Beach during the 1986 pump-out of Brandt Island and maintenance of the Inner Harbor. Of this total, 2,876,300 cubic yards, or 69 percent, was beach compatible material. The distribution of this material along the shoreline is shown on Figure 7.43. Note that the material was deposited in two main areas, one between baseline stations 90+00 and 180+00 and the other between 180+00 and 240+00. This was done to avoid overfilling the profile under the fishing piers located in the vicinity of station 180+00. As a result, two sets of transition zones were created. As was the case for the 1978 fill, the February 1986, June 1986, and 1993 shorelines are also shown relative to the 1972 shoreline on Figure 7.43. The 1986 fill moved the shoreline an average of 365 feet seaward of the February 1986 shoreline with some areas widened by more than 500 feet. The two sets of transition angles were rather severe with an easternmost transition angle of about 19 degrees and a westernmost transition angle of 6 degrees. The two interior transition angle ranged from about 4 degrees to 5 degrees. Potential transport to the east off of the easternmost transition near Fort Macon could have been 9 times greater than normal immediately following placement while transport to the west off of the westernmost transition could have increased by a factor of 3. Due to the sharpness of the west transition angle, transport to the east out of the transition area would have been minimal immediately following placement. Losses from the fill placement area between 1986 and 1993 totaled 1,486,400 cubic yards, which is equal to 51.7 percent of the total beach compatible material deposited on the shoreline. Of the total loss between 1986 and 1993, 809,000 cubic yards was lost from the placement area east of the nodal point (baseline station 151+00). This material was probably transported back into Beaufort Inlet. Losses from the nodal point west to baseline station 240+00 totaled 677,400 cubic yards. The beach area between baseline station 240+00 and 340+00, which was outside the placement limits of the 1986 disposal operation, gained 431,700 cubic yards indicating that some of the material lost from the nodal point to station 240+00 moved to the west.

7.44. 1994 Disposal. The 1994 beach disposal operation pumped a total of 4,664,400 cubic yards to the east end of Bogue Banks of which approximately 1,664,900cubic yards pumped to the Fort Macon shoreline and the remaining 2,999,500 cubic yards pumped to the west end of Atlantic Beach. The volume of beach compatible material placed on these two shoreline segments, again based on an overall compatibility factor of 69 percent, was 1,148,800 cubic yards in front of Fort Macon and 2,069,600 on the Atlantic Beach shoreline between baseline stations 190+00 and 340+00. The Fort Macon fill, which was again located east of the nodal point, initially widened the beach by an average of 340 feet with a maximum shoreline displacement of over 490 feet. The fill placed on the west end of Atlantic Beach averaged 125 feet wide with a maximum width of over 220 feet. The distribution of this fill is shown on Figure 7.44 by comparing the 1993 shoreline to the 1994 shoreline (shorelines plotted relative to the 1972 shoreline). As was the case for the previous beach disposals, the ends of the fills were characterized by rather large transition angles, ranging from about 10 to 12 degrees for the Fort Macon Fill and 4 to 5 degrees for the Atlantic Beach fill. These large transition angles again contributed to the rapid loss of material from the disposal areas. In the case of the fill placed on Fort Macon, approximately 728,300 cubic yards was lost from the fill area by 1996. Comparison of the 1994 post-fill shoreline and the 1996 shoreline on Figure 7.44 shows the lost of approximately 601,500 cubic yards from the west end of Atlantic Beach. Some of this material apparently moved west onto the east end of Pine Knoll Shores. Between 1996 and 1999, the two 1994 fill areas continued to lose material. The Fort Macon placement area lost an additional 627,500 cubic yards resulting in a total volume loss for this area between 1994 and 1999 of 1,355,800 cubic yards, which is greater than the total volume placed in 1994. The Atlantic Beach disposal area also lost and additional 2,016,400 cubic yards between 1996 and 1999 resulting in a total loss from this placement area between 1994 and 1999 of 2,617,900 cubic yards, which was again, greater than the volume placed in 1994.

7.45. Discussion of Fill Performance. A summary of the performance of all three-beach fills is provided in Table 7.4. While the disposal of Morehead City harbor dredged material on the east end of Bogue Banks has substantially improved the condition of this section of the island, the disposal practice, which creates inordinately wide beaches with very sharp transition angles, is not the most efficient use of the material. The analysis of the performance of the three major disposal operations on the east end of Bogue Banks revealed rapid loss of material from the disposal areas. Essentially all of the material placed on the Fort Macon shoreline in 1978 and 1994 appeared to be transported directly into Beaufort Inlet within a few years following disposal. The return of this material to Beaufort Inlet may be partly responsible for the increase in dredging required to maintain the Morehead City Harbor project, but a definitive conclusion in this regard is not possible due to the increased shoaling rates associated with the incremental increases in project depth since 1978. Material placed on Atlantic Beach also experienced rapid loss with a large portion of the material apparently being moved to the west. For all three fills, the total volume of beach compatible material placed on the east end of Bogue Banks was 6,908,700 cubic yards. As of 1999, an estimated 6,267,900 cubic yards had been lost from the placement areas leaving 640,800 cubic yards in place. All of the

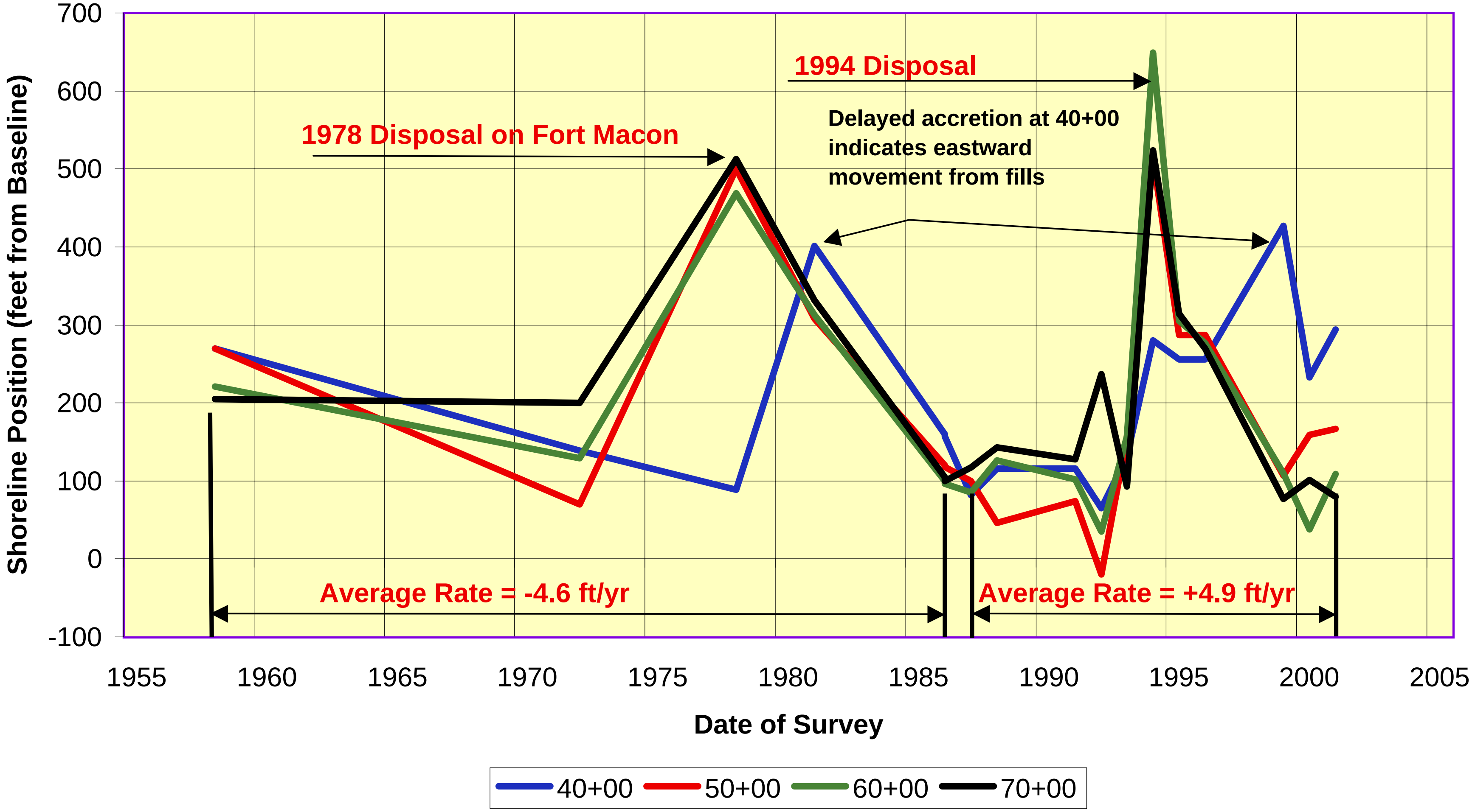
Table 7.4 Summary of Bogue Banks Fill Performance						
Year Fill Placed	**Disposal Area Station to Station**	**Gross Volume Pumped to Beach cy**	**Net Volume Placed on Beach cy**	**Time Period for fill Performance cy**	**Volume Lost during Time Period cy**	**Volume of Fill Remaining on the beach at end of time period (cy)**
		1978 Fort Macon Fill				
1978	**40+00 - 100+00**	**1,179,700**	**814,000**	**1978-1993**	**807,800**	**6,200**
		1986 Brandt Island Pump-Out				
1986	90-150 east of nodal	1,870,000	1,290,300	1986-1993	809,000	481,300
	150-240 west of nodal	2,298,600	1,586,000	1986-1993	677,400	908,600
	90+00 - 240+00 (total)	**4,168,600**	**2,876,300**	**1986-1993**	**1,486,400**	**1,389,900**
	1994 New Work, Maintenance, & Brandt Island Pump-Out					
1994	40+00 - 90+00	1,664,900	1,148,800	1994-1996	728,300	420,500
	190+00 - 340+00	2,999,500	2,069,600	1994-1996	601,500	1,468,100
	Both Areas	**4,664,400**	**3,218,400**	**1994-1996**	**1,329,800**	**1,888,600**
				1996-1999	627,500	-207,000
				1996-1999	2,016,400	-548,300
	Summary 1994 to 1999					
	40+00 - 90+00	1,664,900	1,148,800	1994-1999	1,355,800	-207,000
	190+00 - 340+00	2,999,500	2,069,600	1994-1999	2,617,900	-548,300
	Totals for 1994 Fill (Both Areas)	**4,664,400**	**3,218,400**	**1994-1999**	**3,973,700**	**-755,300**

Figure 7.44 Bogue Banks Shoreline Changes 1972 to 1999
Losses from 1994 fill



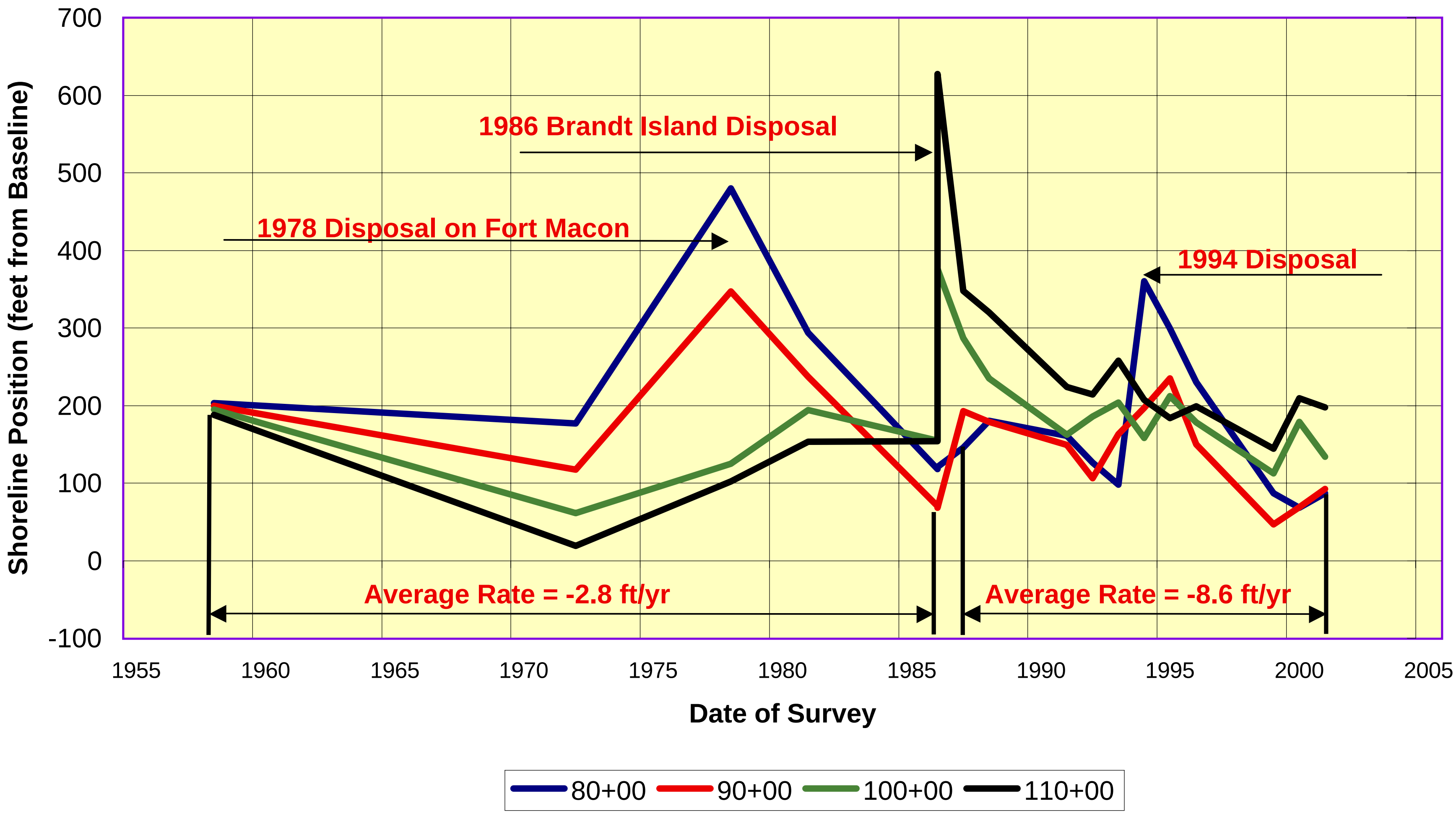
BBSHRLN
72 to 99

Figure 7.45 Bogue Banks MSL Positions versus time
Stations 40+00, 50+00, 60+00, & 70+00
January 1958 to October 2001



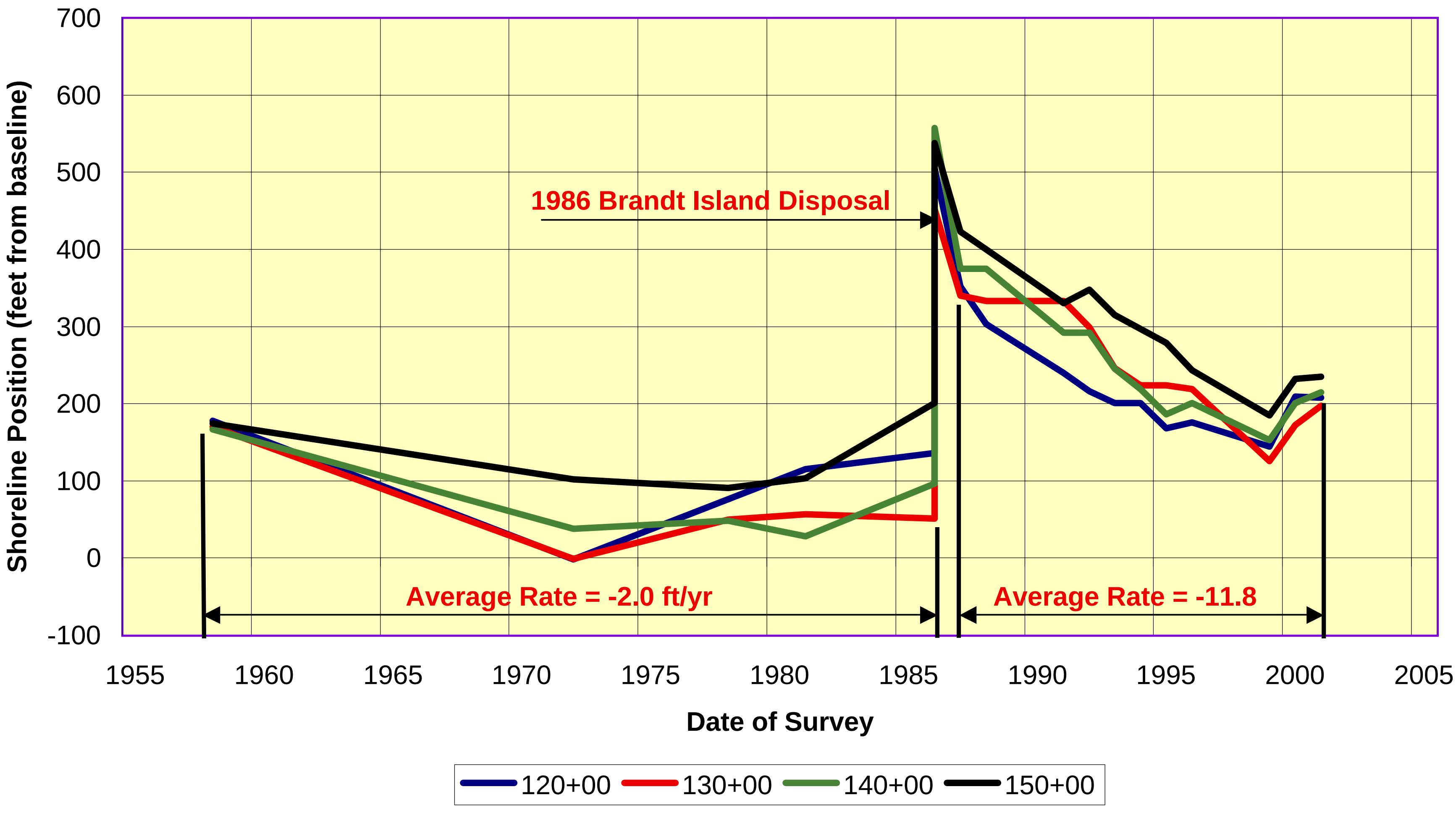
BBSHRLN from surveys.xls
40,50,60,70 vs time

Figure 7.46 Bogue Banks MSL Positions versus time
Stations 80+00, 90+00, 100+00, & 110+00
January 1958 to October 2001



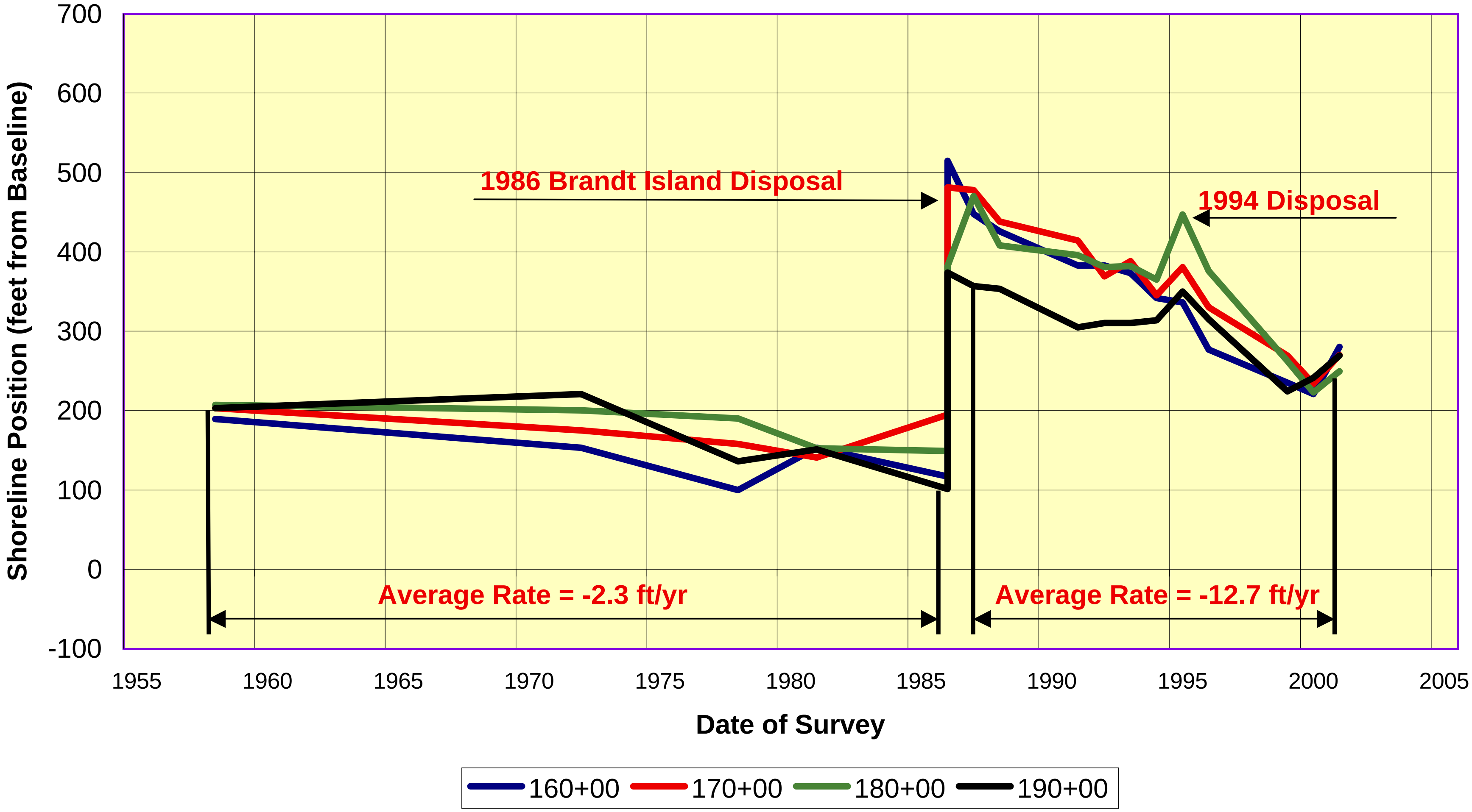
BBSHRLN from surveys.xls
80,90,100,110 vs time

Figure 7.47 Bogue Banks MSL Postions versus time
Stations 120+00, 130+00, 140+00 and 150+00
January 1958 to October 2001



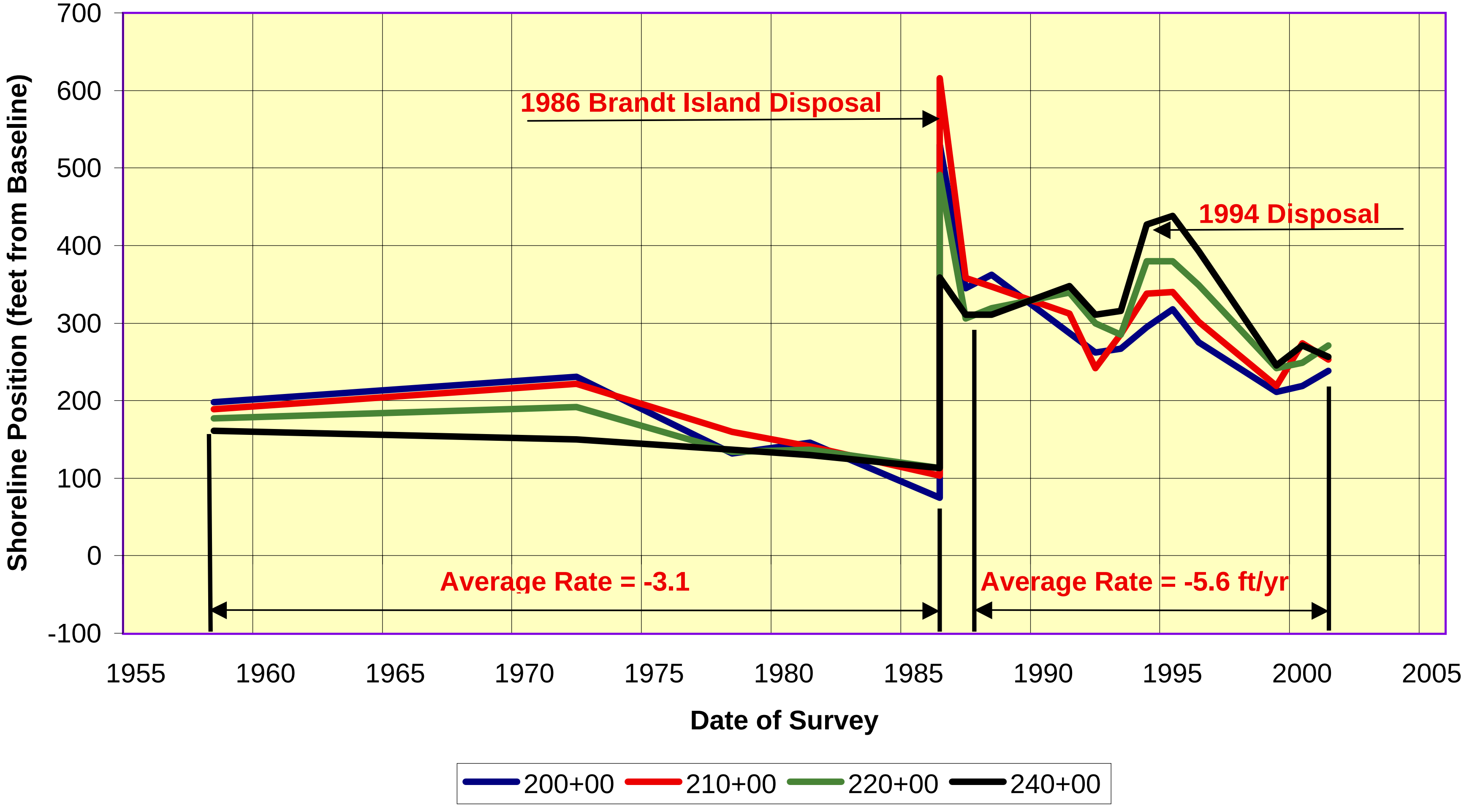
BBSHRLN from surveys.xls
120,130,140,150 vs time

Figure 7.48 Bogue Banks MSL Positions versus time
Stations 160+00, 170+00, 180+00, and 190+00
January 1958 to October 2001



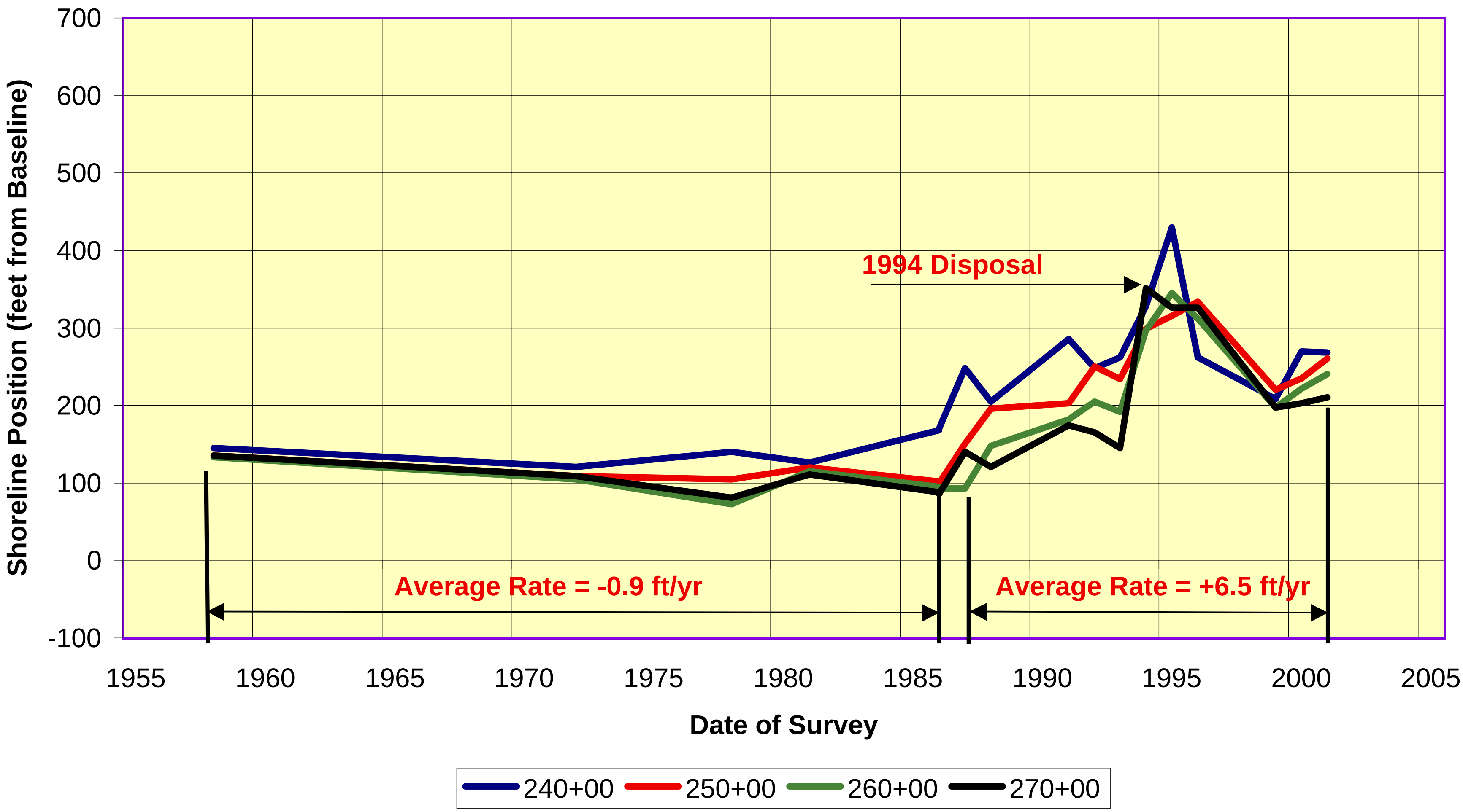
BBSHRLN from surveys.xls
160,170,180,190 vs time

Figure 7.49 Bogue Banks MSL Positions versus time
Stations 200+00, 210+00, 220+00, & 230+00
January 1958 to October 2001



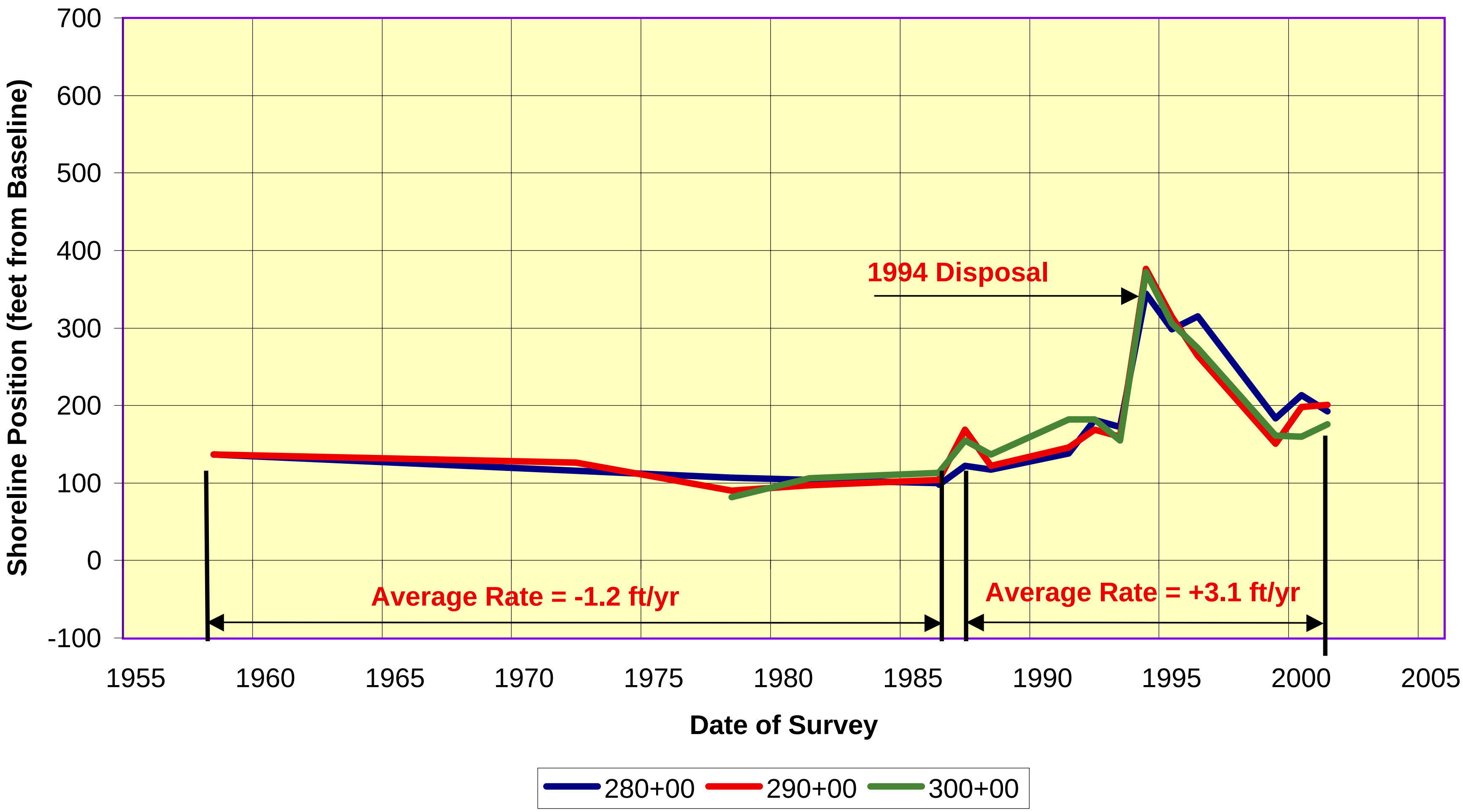
BBSHRLN from surveys.xls
200,210,220,230 vs time

Figure 7.50 Bogue Banks MSL Positions versus time
Stations 240+00, 250+00, 260+00, & 270+00
January 1958 to October 2001



BBSHRLN from surveys.xls
240,250,260,270 vs time

Figure 7.51 Bogue Banks MSL Positions versus time
Stations 280+00, 290+00, 300+00, and 310+00
January 1958 to October 2001



BBSHRLN from surveys.xls
280,290,300 vs time

material remaining in the placement area is located in the area west of the nodal point (station 151+00).

7.46. Time histories of shoreline changes (represented by the 0-foot msl contour) on the east end of Bogue Banks (Atlantic Beach and Fort Macon) for baseline stations 40+00 to 300+00 between 1958 and 2001 are shown on Figures 7.45 to 7.51. These time series graphically illustrate the impact that the disposal operations had on the position of the shoreline and the rapid rate of erosion of the shoreline following each fill placement. While the 0-foot msl contour is located seaward of its 1958 position along most of the area, the rapid rate of shoreline change following each disposal operation indicates that the fills did not perform in an optimal manner. In this regard, the conclusion that material placed east of the nodal point in 1978 and 1994 moved predominantly to the east is supported by the delayed accretion at station 40+00. The performance of future disposal operations could be greatly improved by modifying the manner in which material is distributed along the shoreline. Recommendations for the disposal of the dredged material removed from the Morehead City harbor project are provided later in this report.

7.47. Shoreline Erosion due to Sea Level Rise. The relative rise in sea level has an impact on the rate of shoreline recession in the study area. Per Bruun (1962) theorized that as sea level rises, the beach profile attempts to reestablish the same bottom depths relative to the surface of the sea that existed prior to the rise in sea level. The quantity of material needed to reestablish the beach profile must be derived from erosion of the shore. This theory is expressed by the equation:

$$x\,(e + d) = ab$$

where:

x = rate of shoreline recession due to sea level rise.
e = elevation of the beach berm (= 6 feet msl in the study area).
d = limiting depth between predominant near shore and offshore material transport characteristics (-30 feet in this area)
a = rate of sea level rise.
b = distance from the initial shoreline to the limiting depth (= approximately 3,500 feet).

The rate of sea level rise (a) applicable to the study area is .0086 ft/yr (Corps of Engineers, 1976). Substitution of this rate of sea level rise into the above equation yields a shoreline recession rate of 0.8 feet/year due to sea level rise. Given the wide range of shoreline changes occurring along Bogue Banks and Shackleford Banks, the relative rise in sea level is not a dominant factor controlling shoreline changes in the area.

7.48. Beaufort Inlet Volume Changes-Pre-Project Period. Volumetric changes in the ebb tide delta of Beaufort Inlet were presented in Section 4 of this report. For the 1862 to 1936 pre-project period, volumetric changes on the ebb tide delta outside the influence of the ocean bar channel averaged an accretion of 6,200 cubic yards/year. Basically, this indicates the volume of material on the ebb tide delta remained fairly constant, which would imply that most of the sediment transported to the inlet by littoral currents from both Bogue Banks and Shackleford Banks were not retained on the ebb tide delta. Some material did work its way into the sounds behind the inlet and deposited on the flood tide delta in Back Sound, located behind Shackleford Banks. The 1976 GDM (U.S. Army Corps of Engineers, 1976) contained an estimate of the rate of sediment accumulation in Back Sound based on hydrographic surveys made in 1854 and 1952. This rate was 58,000 cubic yards/year. Due to the relatively small rate of sediment accumulation in Back Sound, an update of volume changes in this area was not performed for this study, rather, the 58,000 cubic yard/year accumulation rate in Back Sound was applied to both the pre-project and with-project time periods. No estimates were made for sediment accumulations on other portions of the flood tide delta of Beaufort Inlet, however, during the pre-project period, some sediment probably did accumulate in the portion of the flood tide delta located in Bogue Sound (see Figure 1.2). In this area, the flood tide delta appears to extend past the highway bridge leading from Morehead City to Atlantic Beach. Assuming that this area of the flood tide delta accumulated sediment at a rate comparable to that of Back Sound, an additional 100,000 cubic yards/year was likely being trapped in this area during the pre-project period. Note that since construction of the Morehead City Harbor inner basins in 1936, sediment now accumulates in the basins and is removed during periodic maintenance dredging. Even though the 1862 to 1936 period is being used to represent pre-project condition, some maintenance dredging was performed to maintain the 20-foot mlw entrance channel. Dredging records presented in Table B-1 of Appendix B, indicate that a total of 2,494,100 cubic yards was removed from the channel between 1911 and 1936. Based on the compatibility analysis of the bar channel shoal material, 86 percent of the shoal material is littoral sand. Therefore, a total of 2,144,900 cubic yards of littoral sediment was removed from the entrance channel and deposited in the ODMDS. Averaging this volume over the entire 74-year pre-project period results in an equivalent rate of maintenance dredging of 29,000 cubic yard/year. For the pre-project period, the total rate of littoral sediment accumulation/removal associated with Beaufort Inlet is given in Table 7.5

Table 7.5
1862 to 1936 Annual Rate of Littoral Sediment Removal by Beaufort Inlet and the Morehead City Harbor Project (Pre-Project Period)

Ebb Tide Delta Change outside the Bar Channel Area	+ 6,200 cy/yr
Sediment Accumulation in Back Sound	+ 58,000 cy/yr
Sediment Accumulation in Bogue Sound	+100,000 cy/yr
Ocean Bar Channel Maintenance Dredging	+ 29,000 cy/yr
Total Rate of Littoral Sediment Removal	**+193,200 cy/yr**

7.49. Beaufort Inlet Volume Changes-With-Project Period. The measured rate of volume loss from the ebb tide delta of Beaufort Inlet between 1974 and 1988 was found to be –61,700 cubic yards/year (see Table 4.1). Applying this rate to the 10-year period from 1978 to 1988 results in an estimated volume loss from this area of the ebb tide delta of 617,000 cubic yards. Losses from the ebb tide delta between 1988 and 2000 were estimated to be 1,950,000 (Table 4.1). Thus, the total estimated volume loss from the ebb tide delta outside the channel area for the 1978 to 2000 time period is 2,567,000 cubic yards *(= 617,000 cy + 1,950,000 cy)*, which is equal to an annual rate of ebb tide delta deflation of -116,700 cubic yards/year. The sediment lost from the ebb tide delta is assumed to deposit either in the ocean bar channel or the inner harbor and subsequently removed and deposited either in the ODMDS or on Brandt Island. Maintenance dredging in the ocean bar channel between 1978 and 2000 removed a total of 14,811,100 cubic yards of material (see Table B-1 in Appendix B). Of this total volume removed, 86 percent was compatible with the native beach sand. Therefore, the volume of littoral sediment removed and deposited in offshore disposal areas outside the active littoral zone of the area was approximately 12,737,500 cubic yards. The equivalent annual rate of littoral sediment removal between 1978 and 2000 was 579,000 cubic yards/year. As mentioned above, sediment accumulation on the portion of the flood tide delta located in Back Sound behind Shackleford Banks, which was 58,000 cubic yards/year, was assumed to be occurring at the same rate for the with-project condition. However, shoaling of the inner basins and channels of Morehead City Harbor replaced the accumulations on the portion of the flood tide delta located in Bogue Sound. Accordingly, the rate of sediment accumulation in this area for the with-project condition is based on the amount of maintenance dredging in the inner harbor and channels. Between 1978 and 2000, a total of 4,604,000 cubic yards of sediment was removed from the inner harbor and deposited on Brandt Island. Since only 69 percent of the shoal material is compatible with the native beach sands, the volume of littoral sediment removed by this maintenance activity was approximately 3,176,800 cubic yards or an average of 144,400 cubic yards/year. The construction of the 40-foot project in 1978, the pump-out of Brandt Island in 1986, and the multiple operation associated with the construction of the 45-foot project in 1994 placed a total of 6,908,700 cubic yards of beach compatible material on the shorelines fronting the Fort Macon State Park and the Town of Atlantic Beach. The equivalent annual rate for the disposal of this quantity of material over the 22-year period from 1978 to 2000 is 314,000 cubic yards/year. The disposal of this material on the beach is credited as having been returned to the littoral system. The rate at which littoral sediment was removed from the littoral system adjacent to Beaufort Inlet between 1978 and 2000 is summarized in Table 7.6.

Table 7.6
1978 to 2000 Annual Rate of Littoral Sediment Removal by Beaufort Inlet and the Morehead City Harbor Project (With-Project Period)

Ebb Tide Delta Change outside the Bar Channel Area	-116,700 cy/yr
Sediment Accumulation in Back Sound	+ 58,000 cy/yr
Ocean Bar Channel Maintenance Dredging	+579,000 cy/yr
Inner Harbor Maintenance Dredging	+144,400 cy/yr
1978, 1986, & 1994 Beach Disposals	-314,000 cy/yr
Total Rate of Littoral Sediment Removal	**+350,700 cy/yr**

7.50. Comparison of Pre-Project and With Project Volume Changes in Beaufort Inlet. The construction and maintenance activities associated with the Morehead City Harbor project has increased the volume rate at which material is being removed from the littoral system by the Beaufort Inlet complex. The Beaufort Inlet complex includes the ebb and flood tide deltas. During the pre-project period, the inlet complex was responsible for the removal of 193,200 cubic yards/year with most of this material stored in the flood tide delta located in Back Sound and Bogue Sound. Between 1978 and 2000, the rate at which the volume of littoral material was removed from the littoral system increased by 157,500 cubic yards/year over the pre-project rate. The majority of this increased rate of sediment removal was due to maintenance of the ocean entrance channel with the material being deposited in either the ODMDS or in a near shore disposal site located immediately west of the inlet in approximately 25-feet of water. The material placed in the ODMDS is completely removed from the littoral system. While placement of material in the near shore disposal site does not theoretically remove it from the littoral environment, very little movement of the deposited material has been noted thus far, so in effect, the volume of material placed in the near shore site since 1997, estimated to be 1,000,000 cubic yards, has also been taken out of the active littoral transport zone. The 1978, 1986, and 1994 beach disposal operations, which placed over 6.9 million cubic yards of beach compatible material on the shorelines of Atlantic Beach and Fort Macon, partially offset the volume of littoral sediment being removed by the harbor project.

8.0 SUMMARY OF FINDINGS

8.1. General. The advent of major harbor improvements in 1936 and subsequent deepening projects in 1961, 1978, and 1994 have altered the normal process of Beaufort Inlet and has greatly modified the inlet morphology. By maintaining the ocean bar channel along a fixed alignment, natural fluctuations in the channel alignment and position, which was a major mechanism that transported sediment across the inlet, no longer occur. The ocean bar channel maintenance practice has also resulted in a reconfiguration of the planform shape of the ebb tide delta. Significant findings of this study regarding the impact of the Morehead City Harbor project on the shore and inlet process are summarized below.

8.2. Littoral Sediment Removal. Over the 64-year period from 1936 to 2000, during which time the channels and basins associated with the Morehead City Harbor project were incrementally deepened and widened, the operation and maintenance of the project resulted in the net removal of an average of 409,300 cubic yards/year of littoral material from the littoral system adjacent to Beaufort Inlet. This rate of littoral sediment removal is 216,100 cubic yards/year greater than the pre-project rate of littoral sediment removal attributable to the inlet. Recently, the annual net rate of sediment removal has been ameliorated to some extent by the disposal of dredged material from the Morehead City Harbor project on the shorelines of Atlantic Beach and Fort Macon. The present net rate of littoral sediment removal attributable to Beaufort Inlet and the Morehead City Harbor project is 350,700 cubic yards/year or 157,500 cubic yards/year greater than the pre-project rate.

8.3. Beaufort Inlet Ebb Tide Delta Deflation and Near Shore Depth Changes. Construction, operation, and maintenance of the Morehead City Harbor project has caused the gradual deepening or deflation of the ebb tide delta of Beaufort Inlet. The deflation of the ebb tide delta was first noted in the GDM for the 40-foot project published in 1976. The 1990 Feasibility Report for the 45-foot project also documented continued deflation of the ebb delta. While a complete survey of the ebb tide delta was not made for this study, the surveys of the offshore profiles on the east end of Bogue Banks and the west end of Shackleford Banks, which included transects across portions of the ebb tide delta, provided evidence that depths over the delta are continuing to increase. The deflation of the ebb tide delta has been accompanied by deepening of the offshore profiles seaward of the eastern 6 to 7 miles of Bogue Banks and along the entire length of Shackleford Banks. The deepening of the offshore profiles on Bogue Banks appear to be directly attributable to the deflation of the ebb tide delta as the ebb tide delta serves as a control or boundary condition for profile depths west of the inlet. In this regard, the greatest amount of profile deepening occurred near Beaufort Inlet with the increased profile depths diminishing west of the inlet. The lineal extent of the ebb tide delta on bottom depths off Shackleford Banks was not discernable from the offshore changes observed between July 1991 and October 2000 as the average increase in profile depth was almost uniform for the entire length of the island. Unlike the east end of Bogue Banks, the area offshore of Shackleford Banks has two boundary conditions that could influence offshore profile depths. In addition to Beaufort Inlet, depths off

Shackleford Banks are influenced or controlled by depths in and around Barden Inlet and the Cape Lookout Bight area. Information on offshore depth changes in these areas was not available for this study. The amount of profile deepening 2 miles east of Beaufort Inlet during approximately the last 9 years was approximately one-half as large as the profile deepening observed over a comparable area on Bogue Banks west of the inlet. This differential deepening of the profiles east and west of the inlet appears to be consistent with the predominant east to west littoral transport computed for the area.

8.4. Inlet Processes. Prior to the stabilization of the ocean bar channel through Beaufort Inlet by repetitive dredging, the ocean bar channel had a natural tendency to change its orientation from a southeasterly direction to a southwesterly direction. Also, the ebb tide delta of the inlet had a bulbous shape that did not extend very far offshore. The natural fluctuations in the orientation of the bar channel was one of the mechanisms of the inlet to move littoral sediment from one side of the inlet to the other. The stabilization of the bar channel eliminated this natural channel movement as well as the associated natural sediment bypassing. Also, the construction and maintenance of the bar channel along the fixed alignment caused the ebb tide delta to assume a more triangular shape and moved the seaward edge of the delta considerably seaward of its pre-project position. The basic shape of the ebb tide delta has not changed since 1952, however, as discussed above, the depths over the delta have continued to increase. The fixation of the bar channel combined with the bar channel depths, which is now 47 feet below mlw, have essentially stopped natural sediment movement across the inlet.

8.5. Sediment Transport. Changes in sediment transport potential along Bogue Banks and Shackleford Banks were evaluated by applying wave transformation techniques for bathymetric conditions representing pre-project and existing conditions. The pre-project bathymetry was based on an 1862 hydrographic survey of the Beaufort Inlet ebb tide delta and the removal of the ODMDS from the existing offshore bathymetry. Waves originating from the east clockwise around to the southwest with varying heights and periods were transformed toward Bogue Banks and Shackleford Banks with the same wave conditions used for both the pre-project and existing bathymetries. The wave characteristics used in the analysis were from the wave information provided by a 1995 Wave Information Study conducted by the U.S. Army Corps of Engineers Waterways Experiment Station (now known as the U.S. Army Engineer, Research, and Development Center or ERDC). Sediment transport potentials to the east and west were computed every 200 feet along both islands from the results of the wave transformation analysis. In general, the predominant or net direction of littoral transport for most of the study area was found to be from east to west with the exception of the extreme east end of Bogue Banks. Net transport is defined as the difference in sediment transport to the west and east at each point along the shoreline. Along the east end of Bogue Banks, both the pre-project and existing conditions indicated an area where the predominant or net transport direction was to the east. For the pre-project bathymetry, the point where the net transport changed from predominantly west to predominantly east was located approximately 2.6 miles from Beaufort Inlet while the existing bathymetry indicated that this point, commonly referred to as a nodal point, was only 2.3 miles from the inlet, i.e., the nodal point had shifted 0.3 mile closer to Beaufort Inlet. The eastward shift of the nodal point was directly due to the change in shape of the ebb tide delta associated with the harbor project and to a lesser extent the existence of the ODMDS. The sediment transport results east of the nodal point was rather erratic for both the pre-project and existing bathymetry, however, the potential for sediment transport to the east was slightly greater than for the pre-project bathymetry. West of the nodal point, sediment transport potentials showed only minor differences with these differences disappearing at a point 10 miles from Beaufort Inlet. Except for the area located within 2.8 miles west of Beaufort Inlet, the changes in potential sediment transport along Bogue Banks due to changes in the offshore bathymetry caused by the Morehead City Harbor project were minor resulting in the conclusion that the changes in sediment transport potential is not a significant factor and would not cause any measurable changes in the shoreline behavior on Bogue Banks west of this point. Also, any potential shoreline impacts associated with changes in sediment transport within the area 2.8 miles west of Beaufort Inlet have been compensated by the disposal of dredged material from the harbor project.

8.6. On the Shackleford Banks side of the inlet, there was a major change in sediment transport potential along the western end of the island with net sediment transport to the west considerably less for existing conditions compared to the pre-project condition. Over the remainder of Shackleford Banks, sediment transport potential was essentially the same for both conditions.

8.7. Shoreline Changes-Bogue Banks. In order to use Section 111 authority to mitigate for shore damages attributable to a Federal navigation project, there must be a clear indication that the project has had a negative impact on the adjacent shorelines. This indication would normally be in the form of increased shoreline recession rates compared to shoreline changes taking place prior to the project. Comparison of shoreline change rates for the pre-project period and the with-project period did not show any significant increases in shoreline erosion over the eastern 12 miles of the island. With-project Erosion rates along the Fort Macon shoreline were significantly greater than the pre-project rates, however, this increase was due to losses from the 1978 fill place just prior to the 1978 survey used in the with-project shoreline change analysis. Prior to major harbor improvement, the shoreline fronting the Town of Atlantic Beach was accreting at an average rate of 1.4 feet/year. For the with-project period, the Atlantic Beach shoreline was accreting at an average rate of 4.9 feet/year with this accretion attributable to the 1986 and 1994 disposal operations from the Morehead City Harbor project. Since the periodic disposal of dredged material on the east end of Bogue Banks is an integral part of the operation of the Morehead City Harbor project, this feature of the project is credited as having a positive impact on the Atlantic Beach shoreline.

8.8. Shoreline changes for the Town of Pine Knoll Shores were basically the same for the pre-project and with-project period with average shoreline change rates of –2.3 feet/year and –2.6 feet/year respectively. The slight increase in the average erosion rate for the with-project period is within the error limits associated with the shoreline change data used in the analysis and therefore cannot be view as being significant. For the remaining sections of Bogue Banks west of Pine Knoll Shores, the with-project shoreline changes differed significantly from the pre-project changes. Along Indian Beach, the average rate of shoreline recession increased from a pre-project rate of –1.2 feet/year to a with project rate of –3.1 feet/year. East Emerald Isle and West Emerald Isle, which were accreting during the pre-project period, experienced erosion during the with-project period. East Emerald Isle was accreting at a rate of 0.6 feet/year during the pre-project period and eroding at a rate of –2.6 feet/year during the with-project period. West Emerald Isle changed from an accretion rate of 0.3 feet/year to an erosion rate of -1.3 feet/year. Since the potential for sediment transport along this section of Bogue Banks was found to be the same for both the existing conditions and pre-project condition and since the behavior of the Pine Knoll Shores shoreline was essentially the same for both periods, the change in shoreline response along the west half of Bogue Banks is not due to the Morehead City Harbor project. The increased erosion rates along this section of the area are primarily due to the impacts of the 9 severe to moderate tropical storms that impacted the area between 1993 and 1999 and the more local processes associated with Bogue Inlet.

8.9 Shoreline Changes-Shackleford Banks. The shoreline changes occurring on Shackleford Banks during the with-project period have changed considerably from the changes taking place during the pre-project period. During the pre-project period, the shoreline along entire length of Shackleford Banks was eroding with the highest rate, -4.1 feet/year, occurring on the western 10,000 feet of the island. The middle 20,000 feet of the island was eroding at an average rate of –2.3 feet/year and the eastern 9,000 feet –2.5 feet/year. For the with-project period, the shorelines on both the east and west ends of the island accreted at rates of 1.6 feet/year and 1.3 feet/year respectively. Shoreline erosion along the middle part of the island increased, averaging –5.1 feet/year. The build-up on the east and west ends of the island combined with the increased recession along the middle portion has resulted in Shackleford Banks assuming a more concaved shoreline configuration compared to its pre-project shape. In addition, the west end of the island has extended approximately 5,000 feet into Beaufort Inlet. The changes in shoreline behavior on the west and middle portions of the island are strongly associated with the physical changes that have occurred in the shape of the Beaufort Inlet ebb tide delta as a result of the Morehead City Harbor project. Changes on the east end of the island are probably due to changes in Barden Inlet and Lookout Bight, however, no data was available to determine what changes may have occurred in these areas. While the various sections of the island are behaving differently, island-wide, the average shoreline changes for the with-project period have been less than the changes measured for the pre-project period. For the pre-project period, the average erosion rate along the entire island was –2.8 feet/year while the with-project period average rate was only –1.8 feet/year. As mentioned previously, the behavior of the shoreline along Shackleford Banks was not reflected in changes in the offshore bottom as the offshore profiles taken between July 1991 and October 2000 indicated significant deepening and associated volume loss.

9.0 CONCLUSIONS

9.1. General. The construction, operation, and maintenance of the Morehead City Harbor project has caused significant physical changes in the configuration of the Beaufort Inlet ebb tide delta and has altered the ability of the inlet to naturally bypass sediment from one side of the inlet to the other. The harbor project is also responsible for the net removal of large quantities of littoral sediment from the area. However, the removal of this sediment has not negatively impacted the shorelines on either side of Beaufort Inlet. In particular, the shoreline change rates along the shoreline fronting the Town of Pine Knoll Shores, the entity that requested this study, were found to be statistically the same for the pre-project and with-project periods. The major impacts determined from this study have been the gradual deepening or deflation of the Beaufort Inlet ebb tide delta and the accompanying deepening of the near shore beach profiles 6 to 7 miles west of the inlet and at least 5 to 6 miles east of the inlet. Without any change in the dredged material disposal practices for the harbor project, these impacts will likely continue.

9.2. The disposal of dredged material removed from the harbor project on the shorelines of the Town of Atlantic Beach has effectively improved the condition of this beach relative to the pre-project condition. However, the disposal practice, which has been to concentrate the disposal over relatively small shoreline reaches, has resulted in the rapid rate of loss of material from the disposal areas. Also, there is some evidence that material placed on the Fort Macon shoreline, which lies east of the sediment transport nodal zone, is transported directly back into Beaufort Inlet at accelerated rates. The rapid return of this material to the inlet could be a factor contributing to the shoaling of the entrance channel and inner basin, however, data to support this was not available.

9.3. While the Morehead City Harbor project has significantly altered normal inlet and shore processes of the area, there is no direct evidence that the harbor project has had a negative impact on the Pine Knoll Shores shoreline or any of the shorelines in the vicinity of the harbor project. Therefore, mitigation for shoreline damages under the authority provided by Section 111 of Public Law 90-483, as amended, is not warranted. Apart from any mitigative element, the sand management practices for the harbor project could be improved to lessen the possible future impacts on the shorelines that could result from the continued deepening of the near shore ocean bottom, which is associated with the deflation of the Beaufort Inlet ebb tide delta. Changes in the disposal practice could include near shore placement of the material removed from the entrance channel and a wider distribution of the material removed from Brandt Island on the east end of Bogue Banks. The near shore placement of the entrance channel material should include areas off the east end of Bogue Banks and the west end of Shackleford Banks. The near shore placement of this material would serve two purposes; namely, a reduction in the rate of ebb tide delta deflation and a diminution in the rate of deepening noted in the offshore profiles of both islands. Distribution of the Brandt Island material over a wider area would greatly reduce the rate of loss from the disposal areas and possibly reduce the rate of sediment transport into Beaufort Inlet. Given the potential for possible project related impacts in the area immediately west of Beaufort Inlet, any change in the disposal plan for the Brandt Island material must continue to include disposal of material along the Atlantic Beach and Fort Macon shorelines. However, the rate of disposal, i.e., the volume placed per lineal foot of shoreline, should be substantially reduced compared to past disposal practices, particularly in the area east of the nodal point. Consideration of alternative disposal plans for the Morehead City Harbor project is beyond the scope of the Section 111 authority and will have to be evaluated in a separate dredged material disposal plan for the harbor project.

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APPENDIX A

SUPPLEMENTAL SHORELINE CHANGE DATA AND PROFILE PLOTS

Figure A-1 Bogue Banks Station 40+00
July 1991 & November 2000
Station 43+10, April 2001

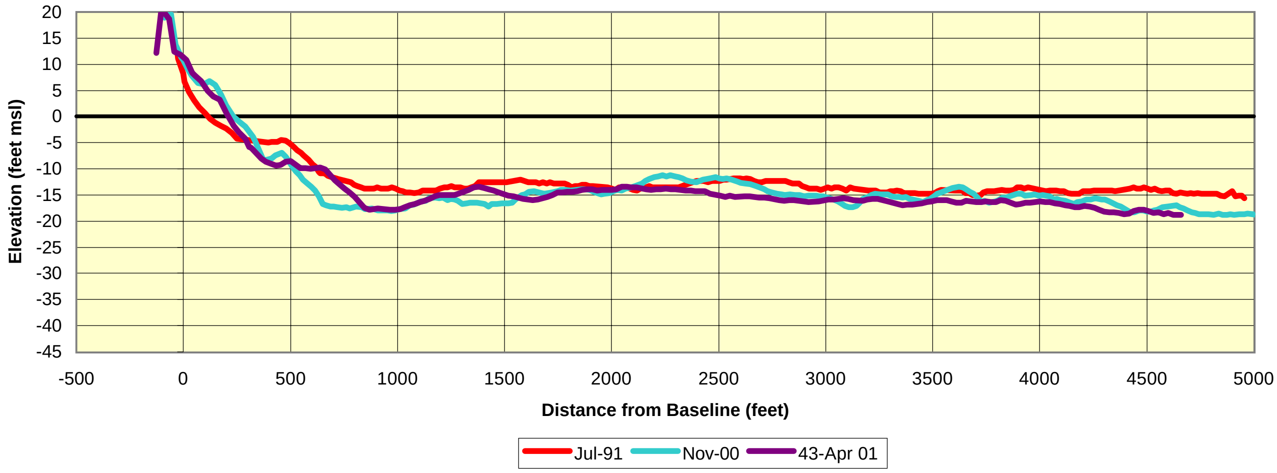


Figure A-2 Bogue Banks Station 60+00
July 1991 & November 2000
Station 63+15, April 2001

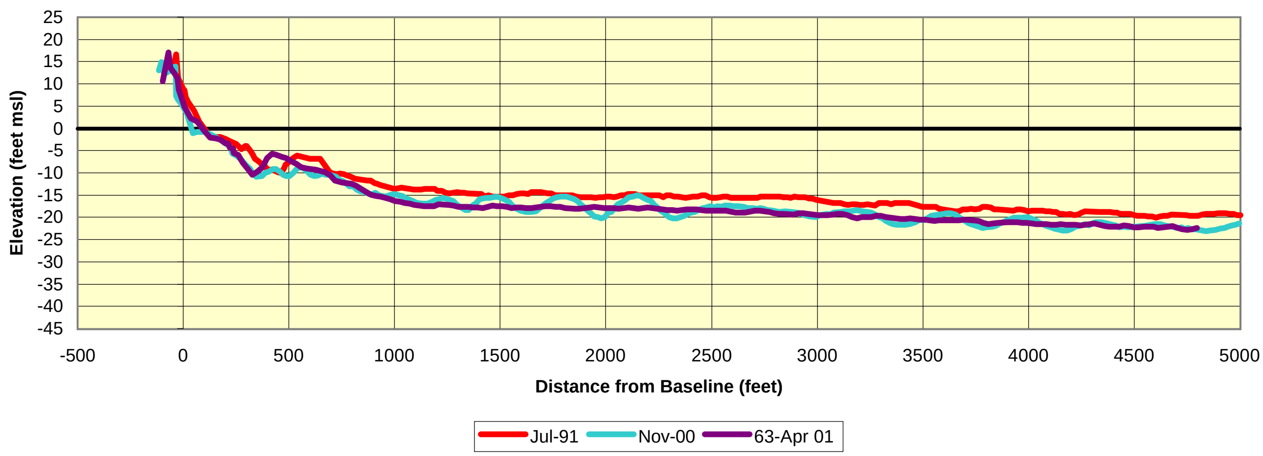


Figure A-3 Bogue Baks Station 80+00
July 1991 and November 2000
Station 83+16, April 2001

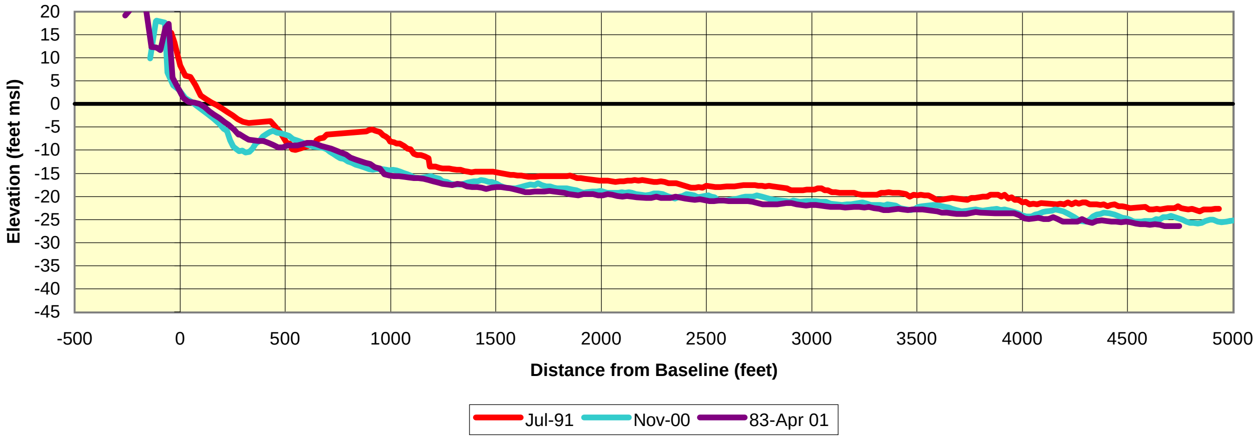


Figure A-4 Bogue Banks Station 90+00
July 1991 and November 2000
Station 93+33, April 2001

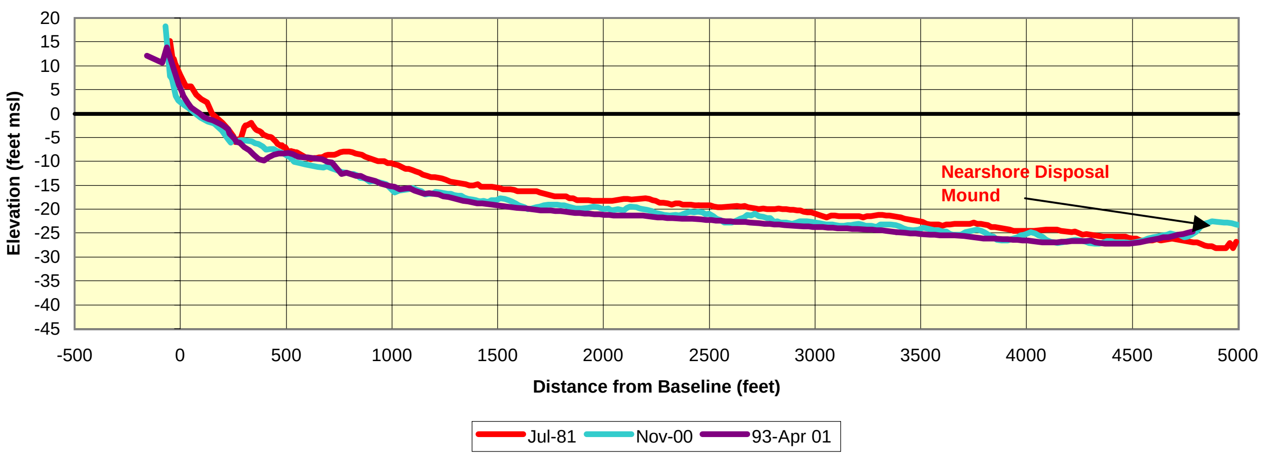


Figure A-5 Bogue Banks Station 110+00
July 1991 and November 2000
Station 113+38, April 2001

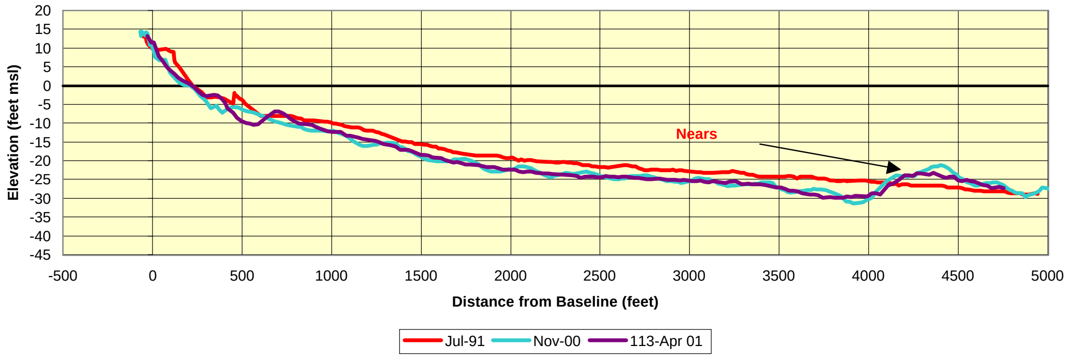


Figure A-6 Bogue Banks Station 130+00 October 1972, July 1991, & November 2000
Station 133+31, April 2001

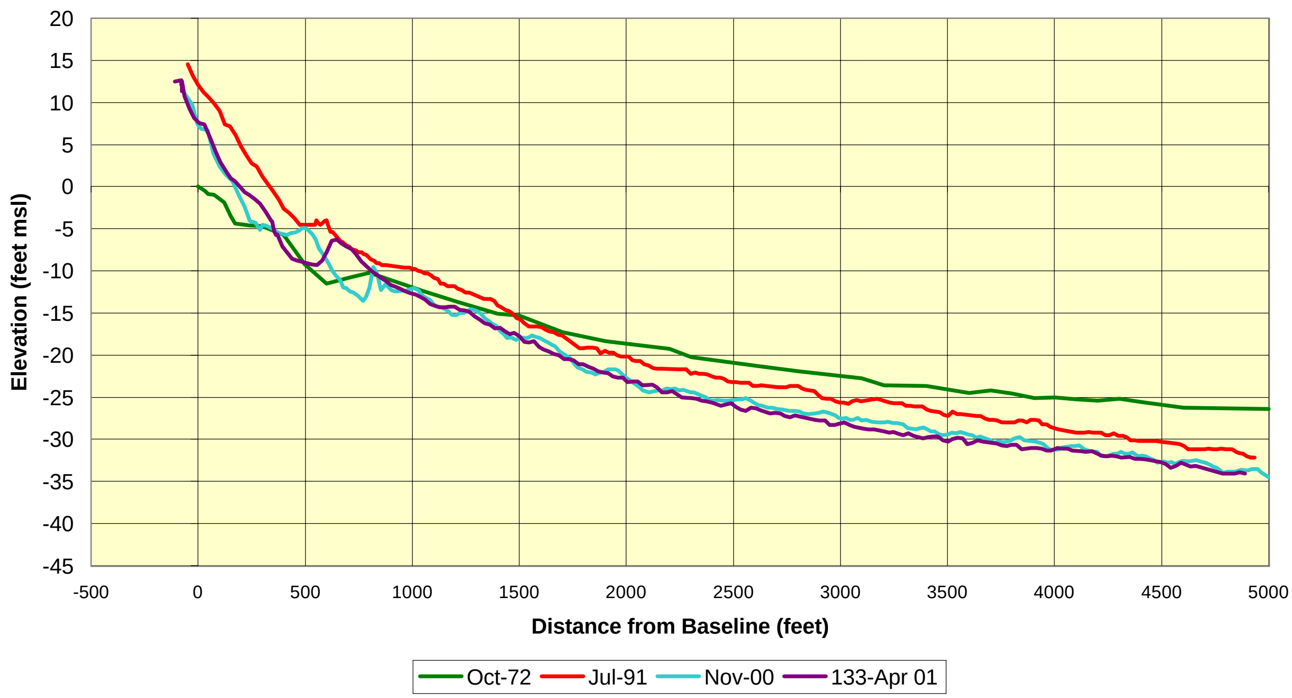


Figure A-7 Bogue Banks Station 190+00
July 1991 and November 2000
Station 193+36, April 2001

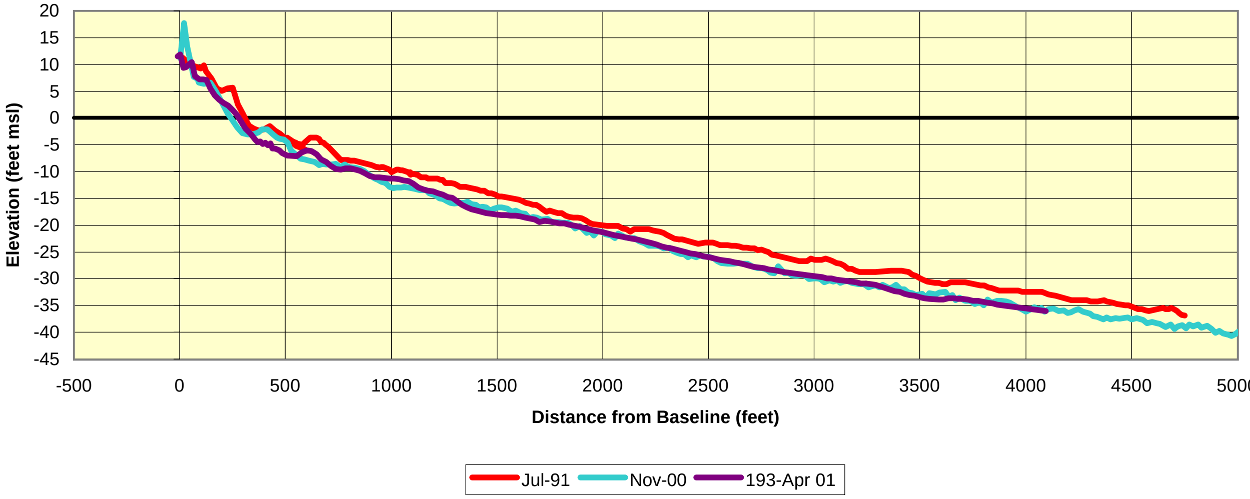


Figure A-8 Bogue Banks Station 200+00
July 1991 and November 2000
Station 203+38, April 2001

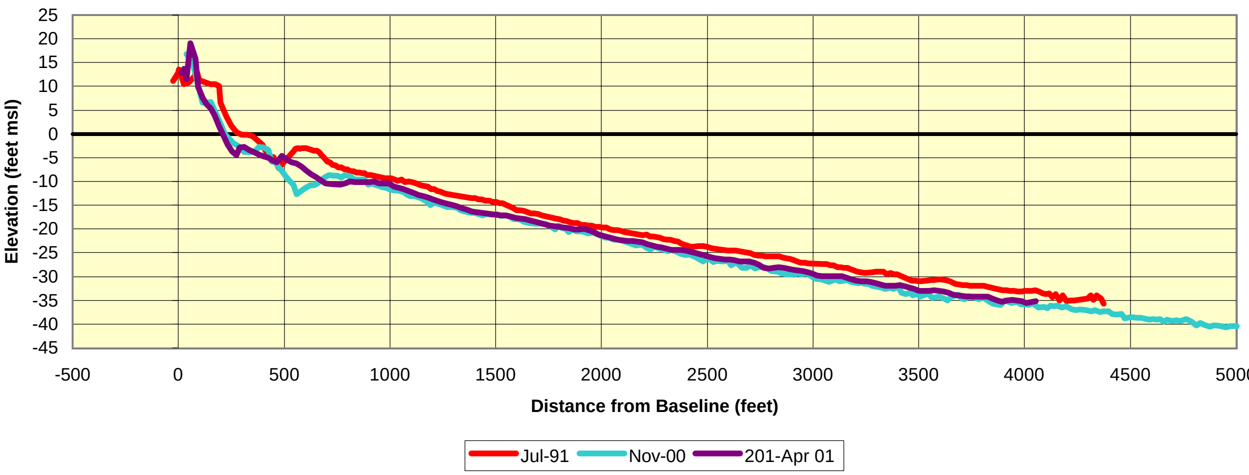


Figure A-9 Bogue Banks Station 210+00
July 1991 and November 2000
Station 213+33, April 2001

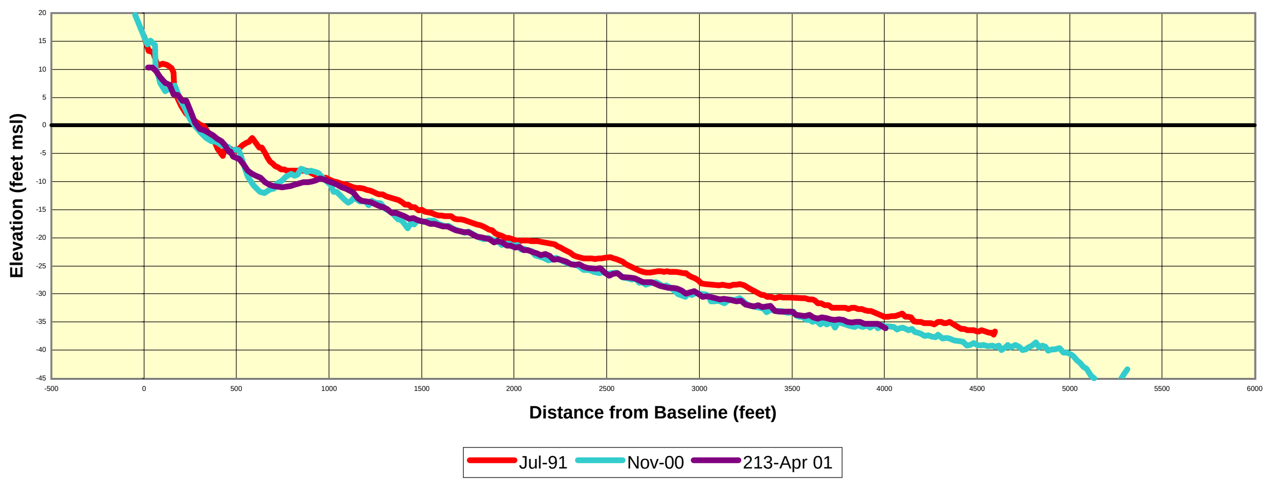


Figure A-10 Bogue Banks Station 230+00
July 1991 and November 2000
Station 233+30, April 2001

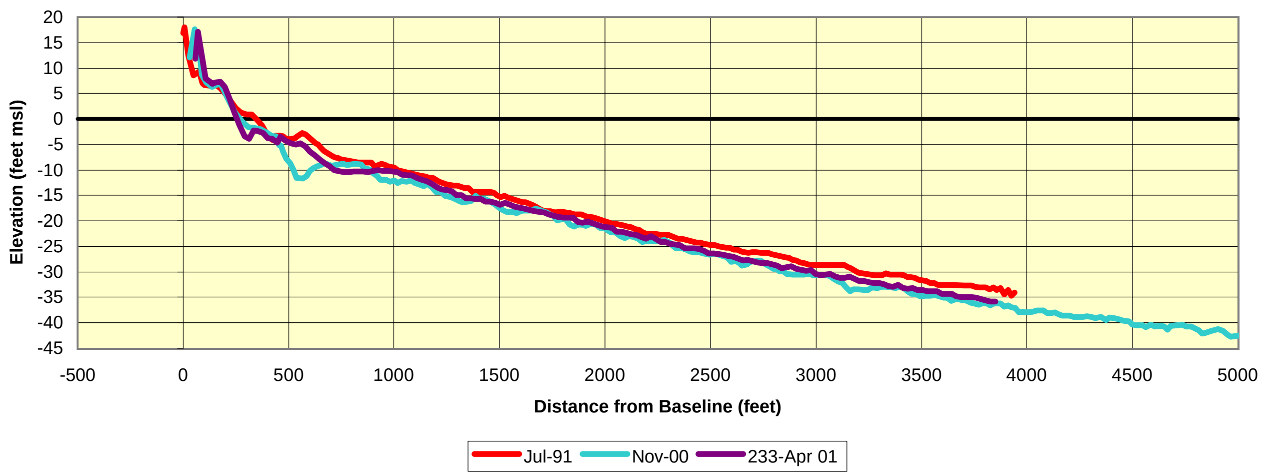


Figure A-11 Bogue Banks Station 240+00
July 1991 and November 2000
Station 243+30, April 2001

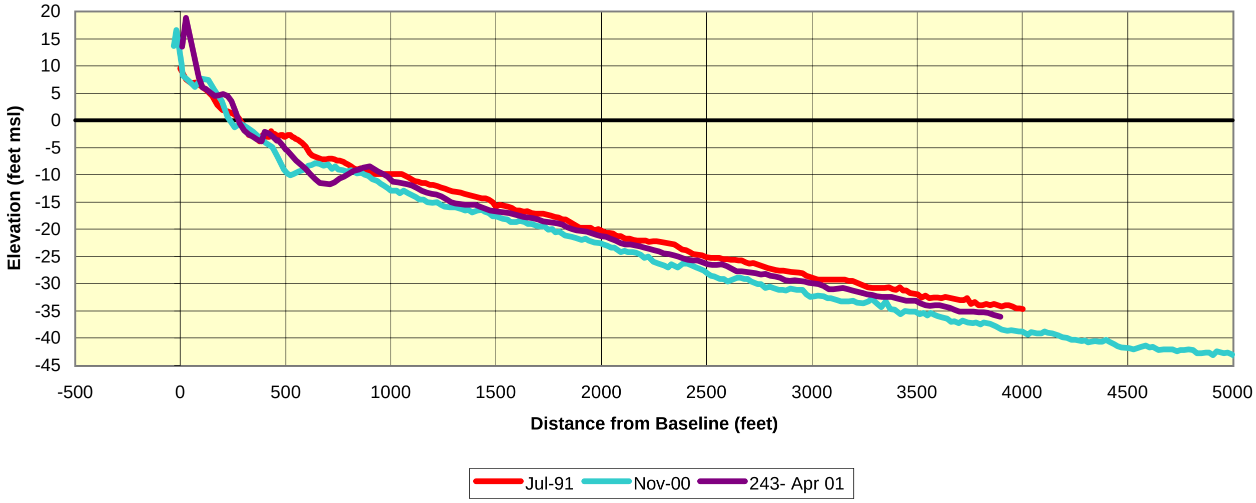


Figure A-12 Bogue Banks Station 260+00
July 1991 and November 2000
Station 263+25, April 2001

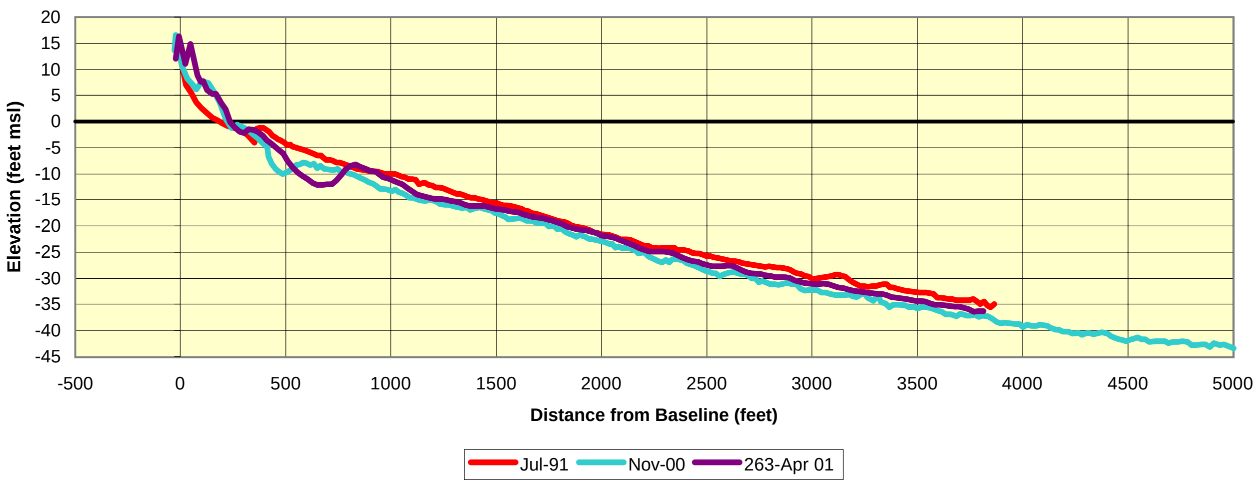


Figure A-13 Bogue Banks Station 270+00
July 1991 and November 2000
Station 273+25, April 2001

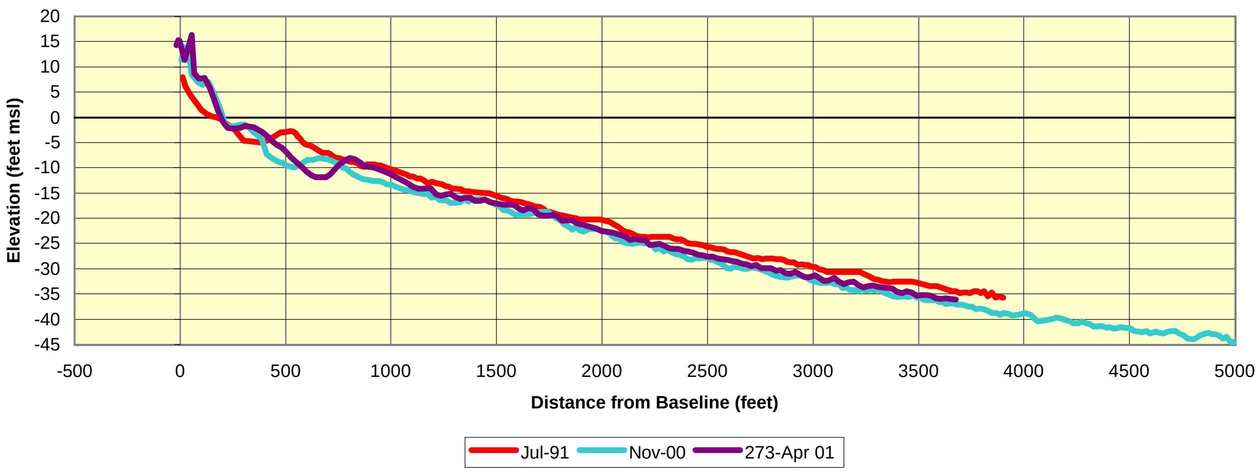


Figure A-14 Bogue Banks Station 280+00
July 1991 and November 2000
Station 283+27, April 2001

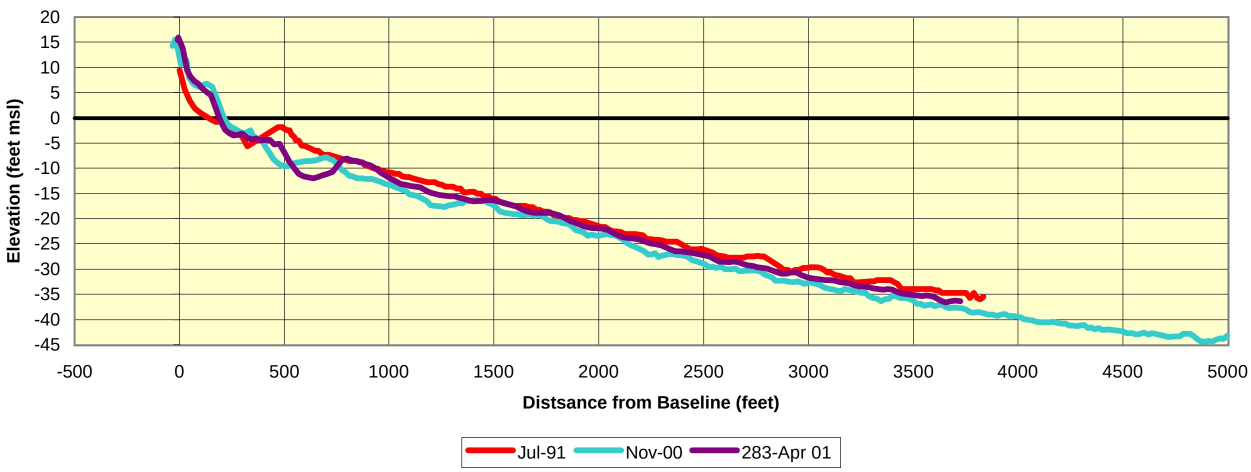


Figure A-15 Bogue Banks Station 300+00
July 1991 and November 2000
Station 302+29, April 2001

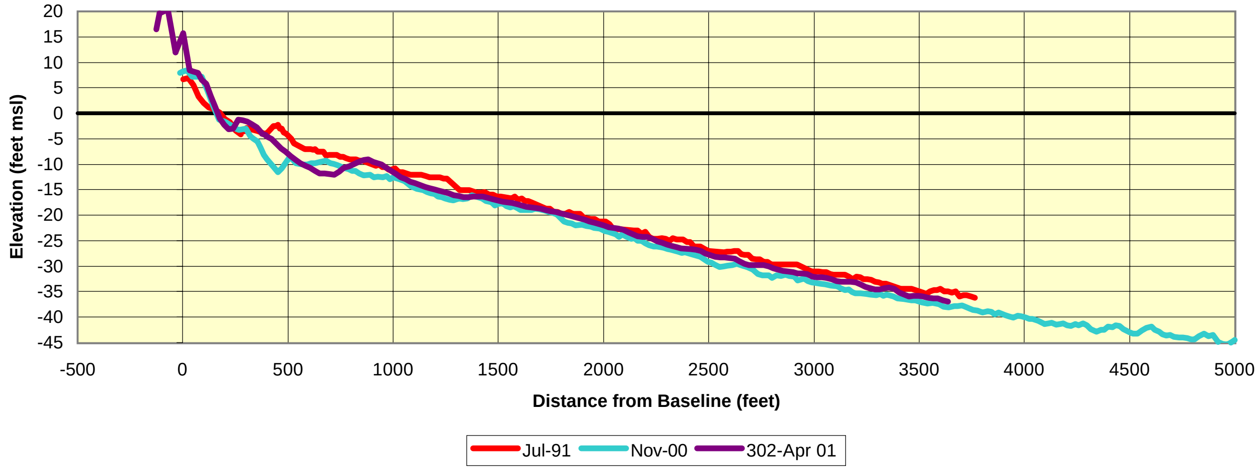
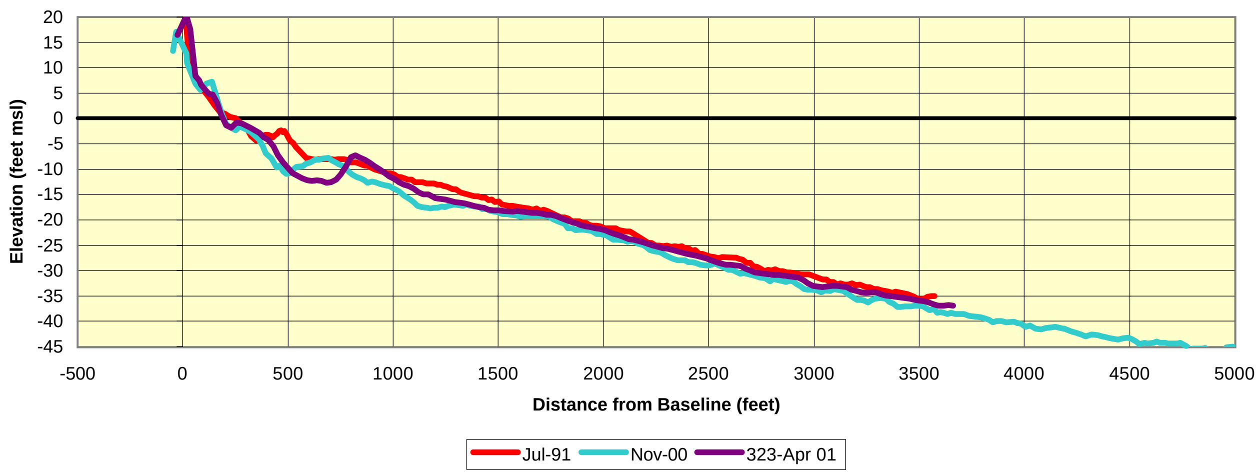


Figure A-16 Bogue Banks Station 318+00
July 1991 and November 2000
Station 323+61, April 2001



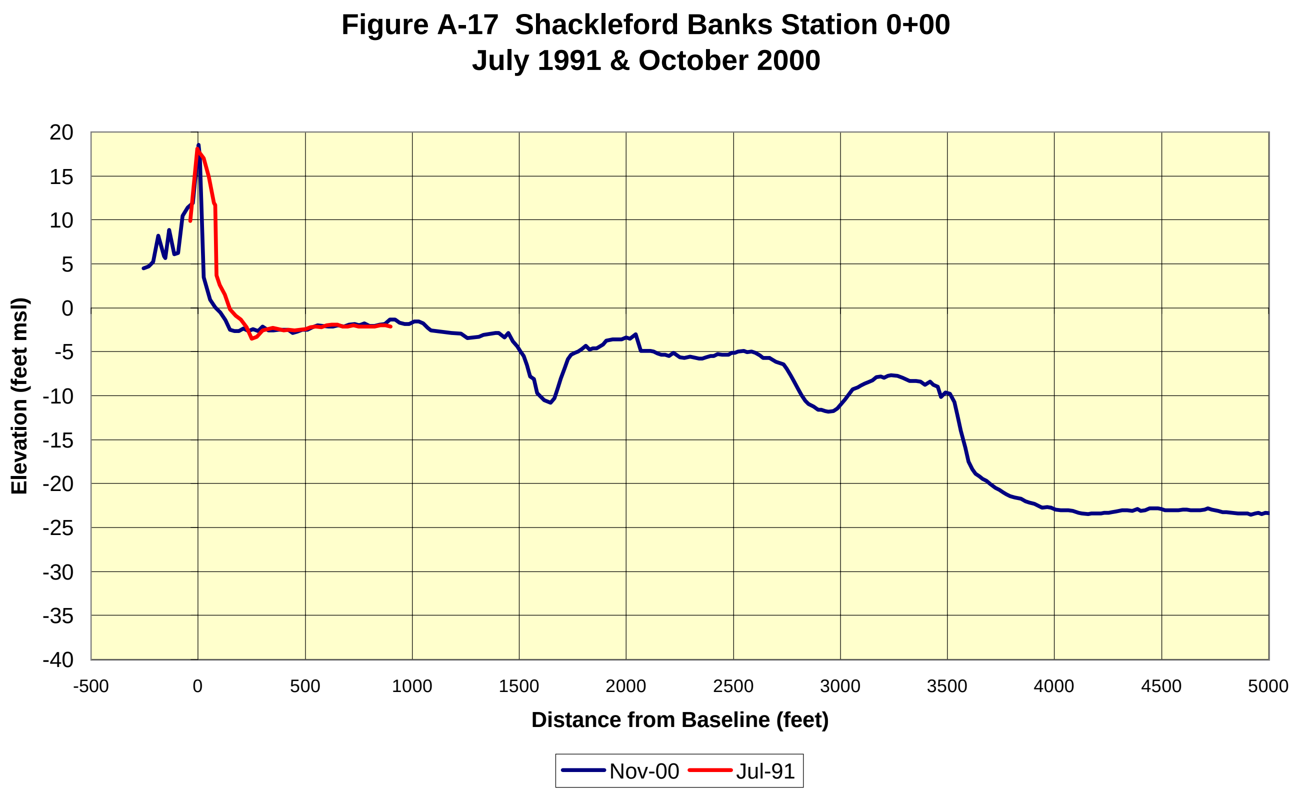


Figure A-17 Shackleford Banks Station 0+00
July 1991 & October 2000
Elevation (feet msl)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance from Baseline (feet)
Nov-00
Jul-91

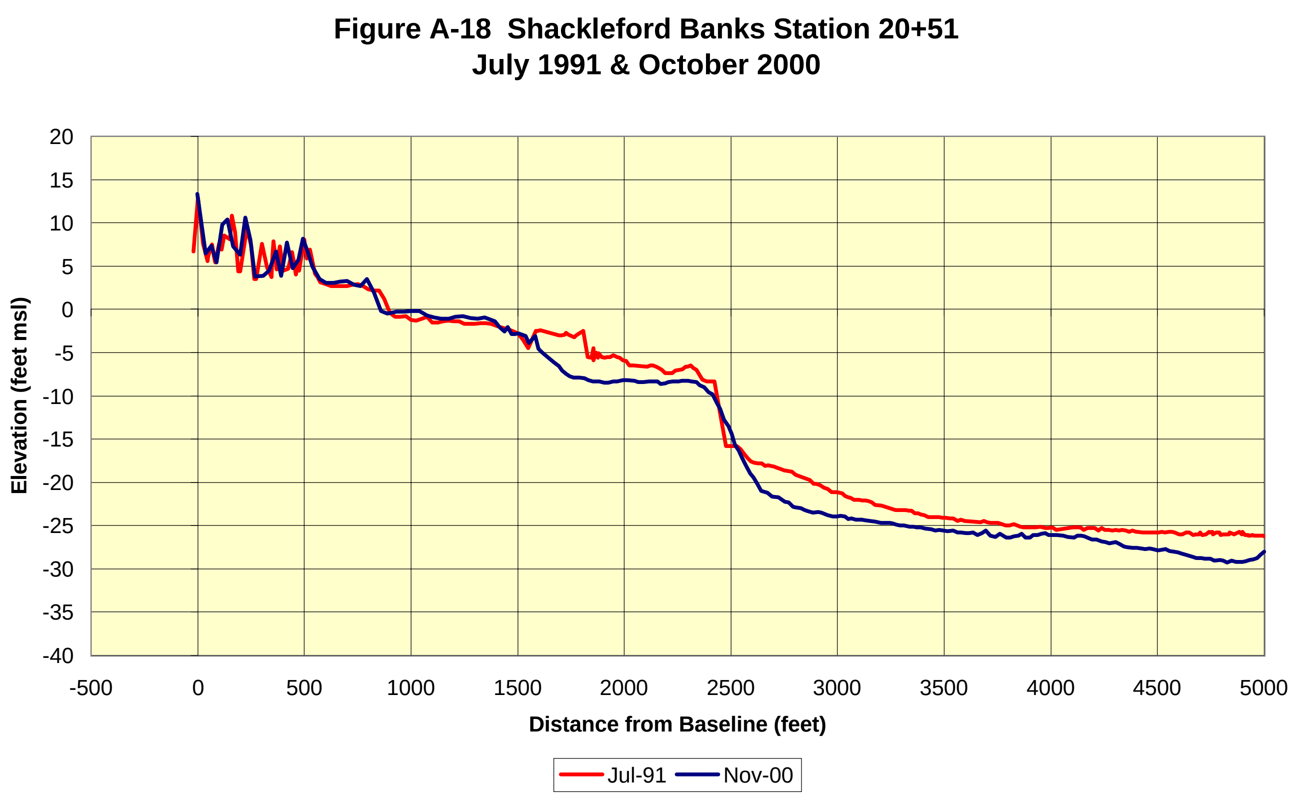


Figure A-18 Shackleford Banks Station 20+51
July 1991 & October 2000
Elevation (feet msl)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance from Baseline (feet)
Jul-91
Nov-00

Figure A-19 Shackleford Banks Station 58+82
July 1991 & October 2000

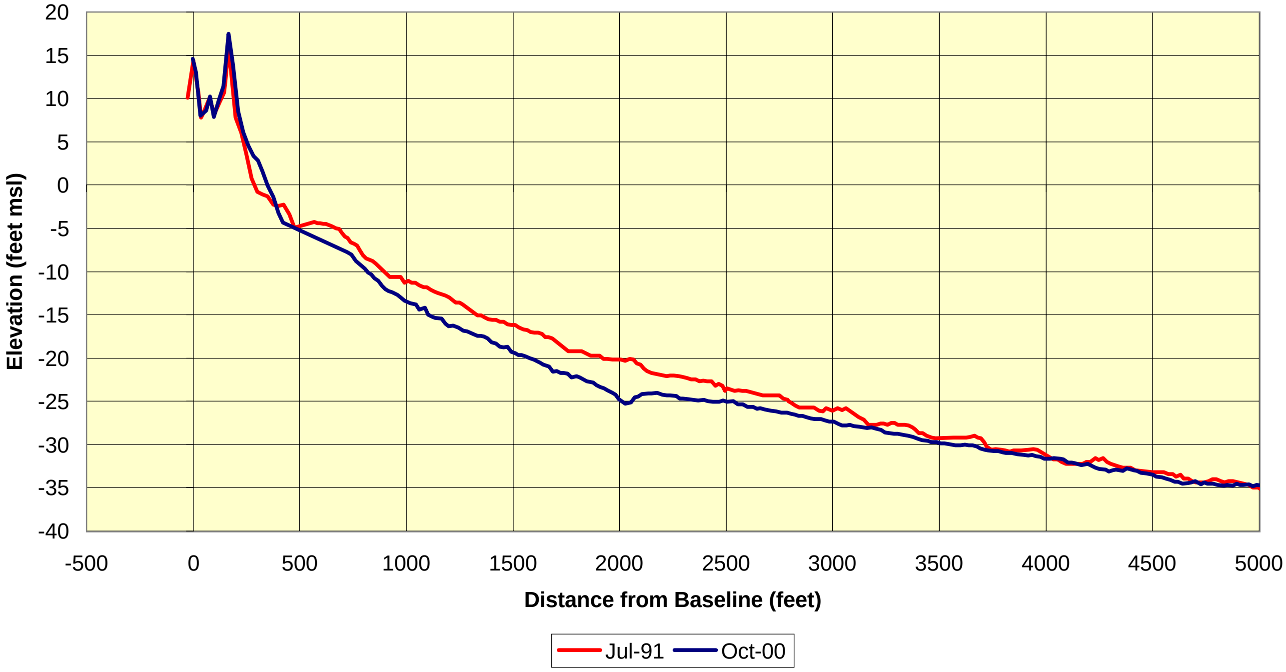


Figure A-20 Shackleford Banks Station 96+76
July 1991 & October 2000

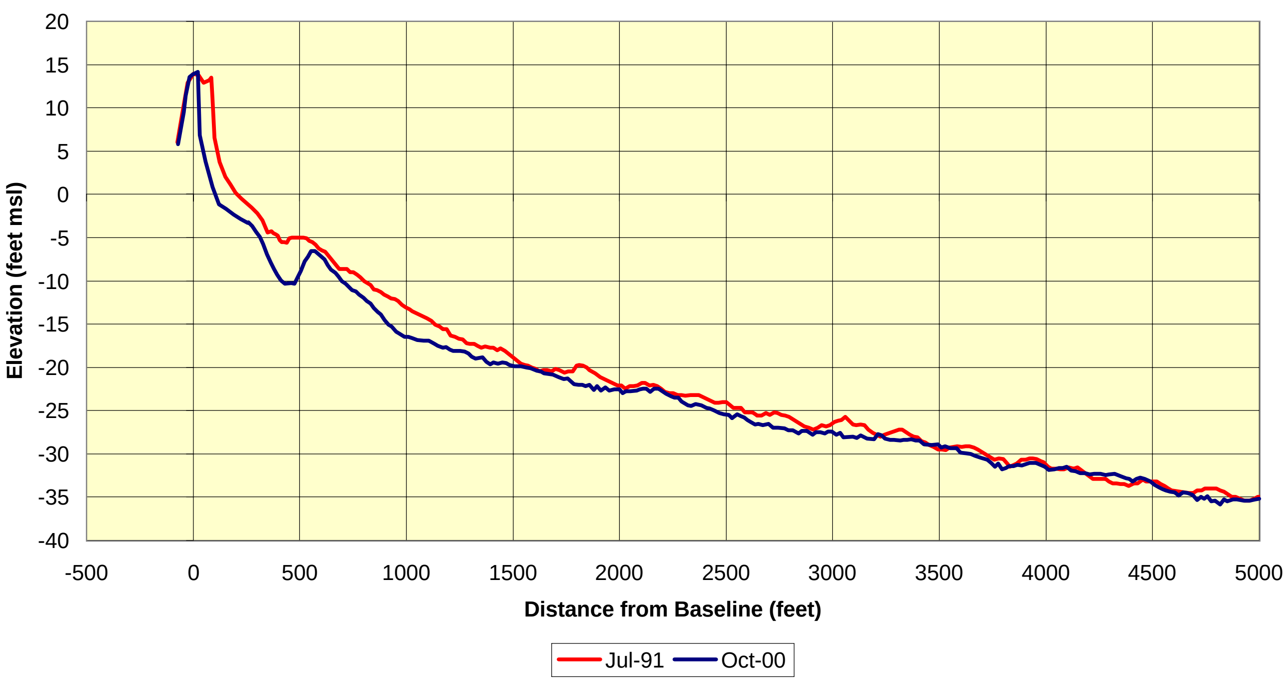


Figure A-21 Shackleford Banks Station 130+01
July 1991 & October 2000

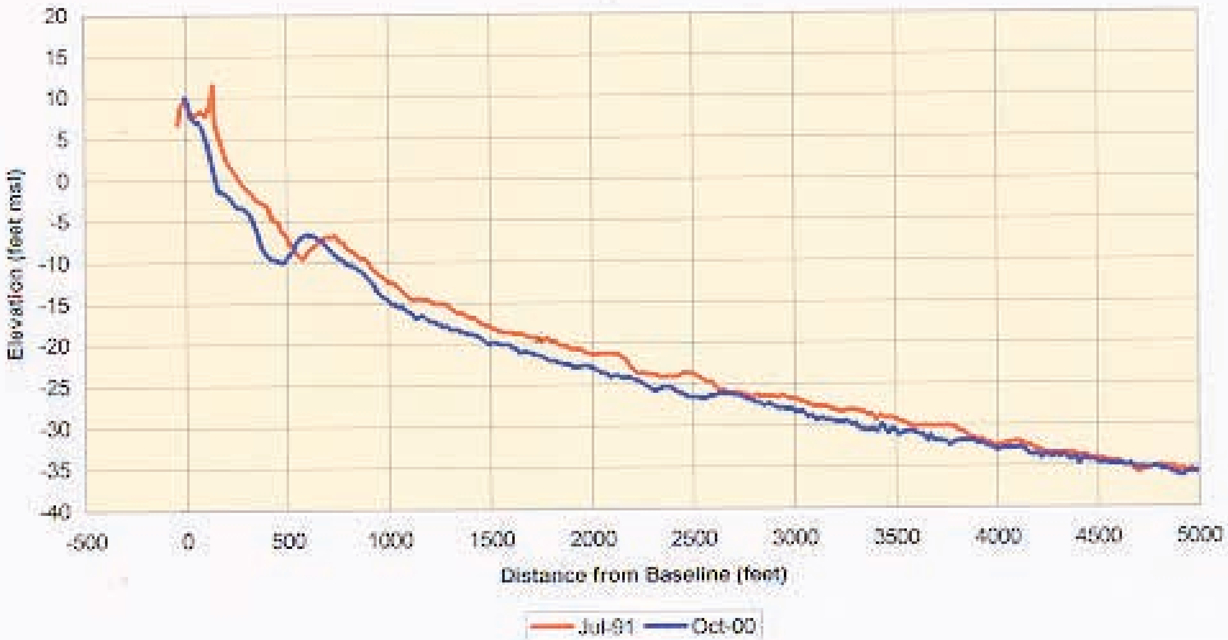


Figure A-22 Shackleford Banks Station 170+79
July 1991 & October 2000

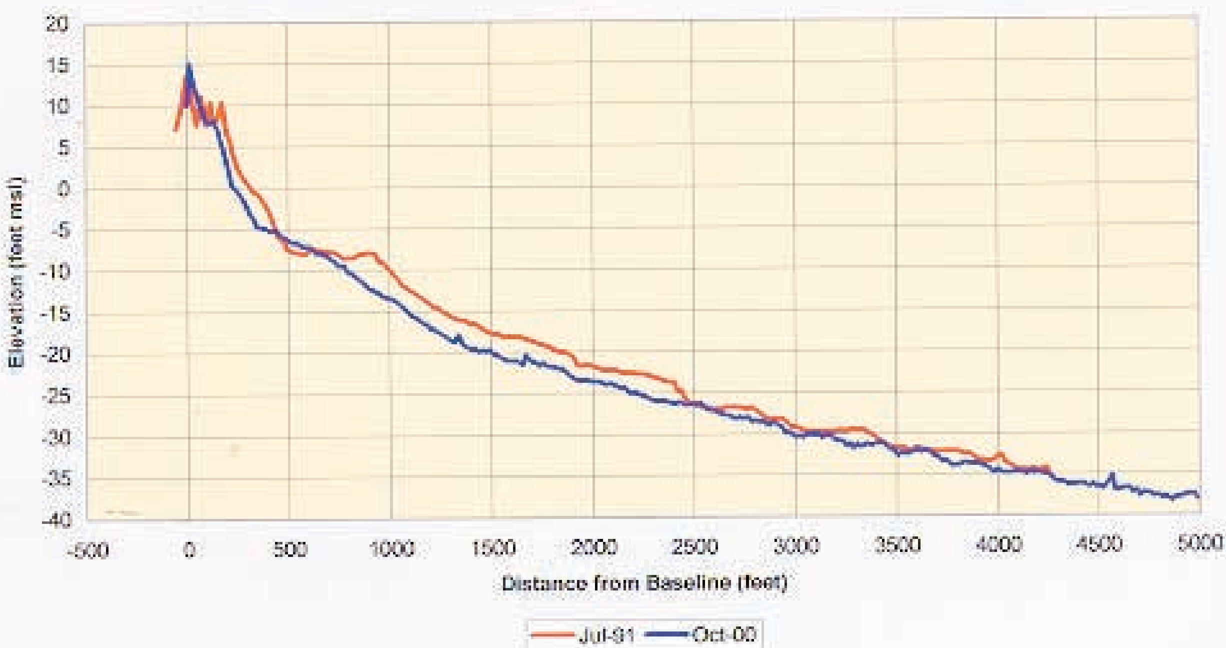


Figure A-23 Shackleford Banks Station 210+08
July 1991 & October 2000

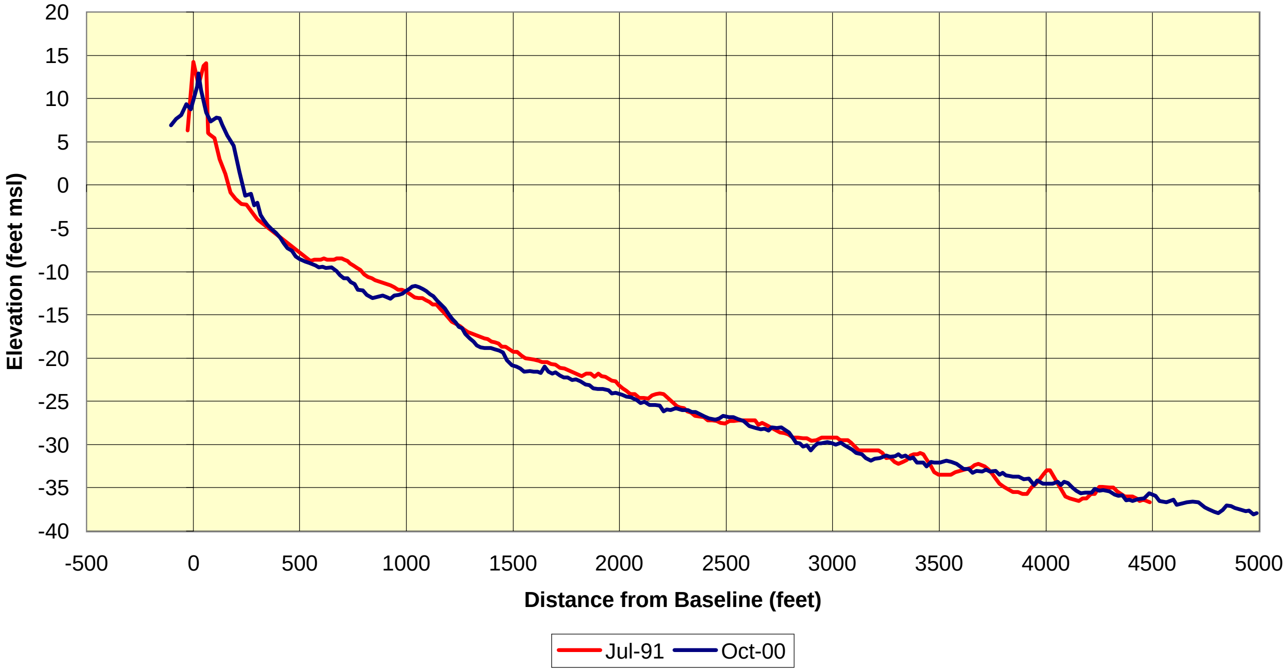


Figure A-24 Shackleford Banks Station 248+67
July 1991 & October 2000

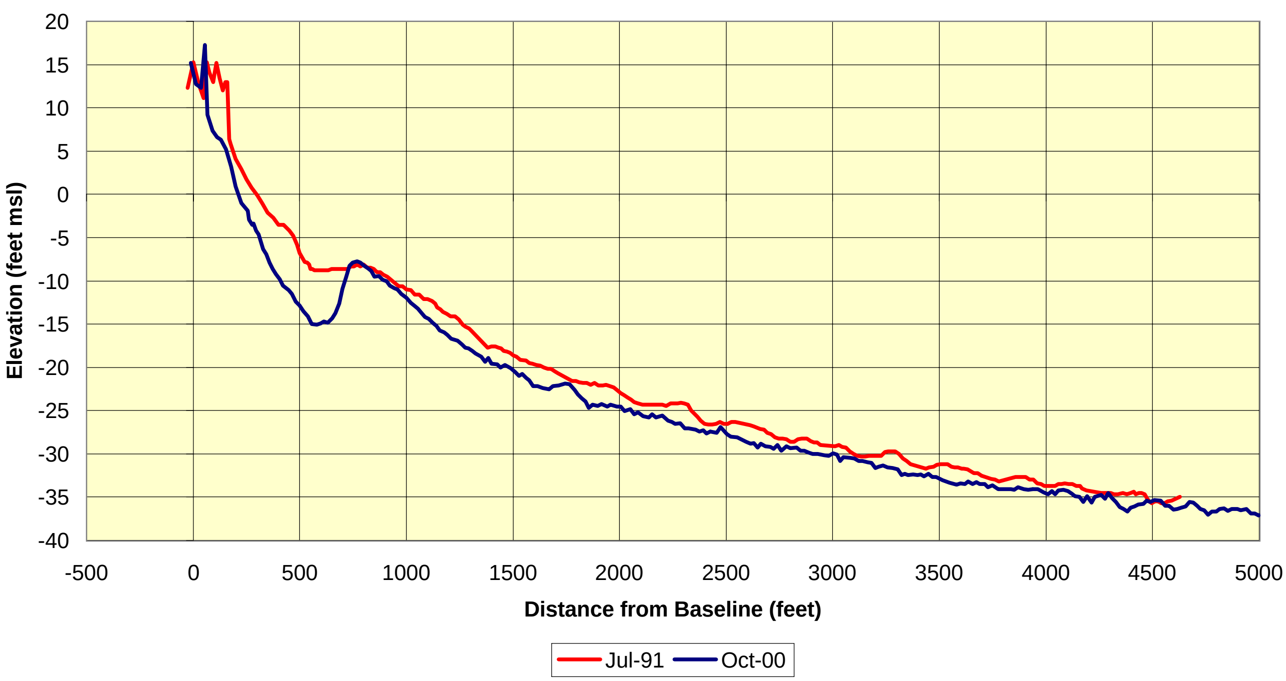


Figure A-25 Shackleford Banks Station 293+38
July 1991 & October 2000

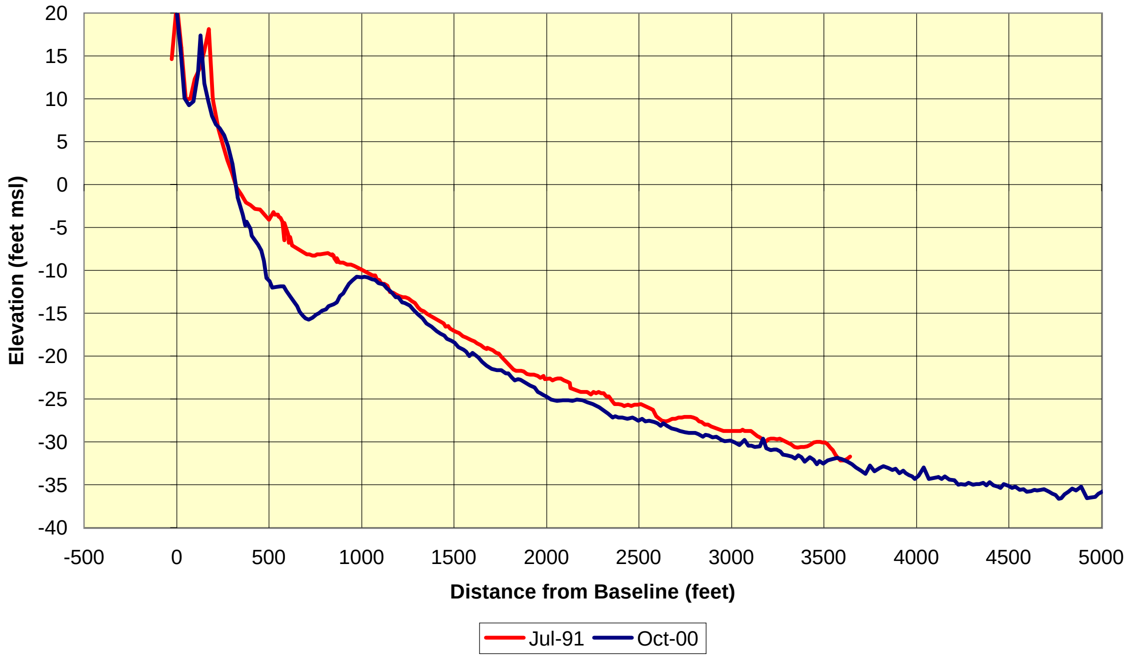


Figure A-26 Shackleford Banks Station 343+08
July 1991 & October 2000

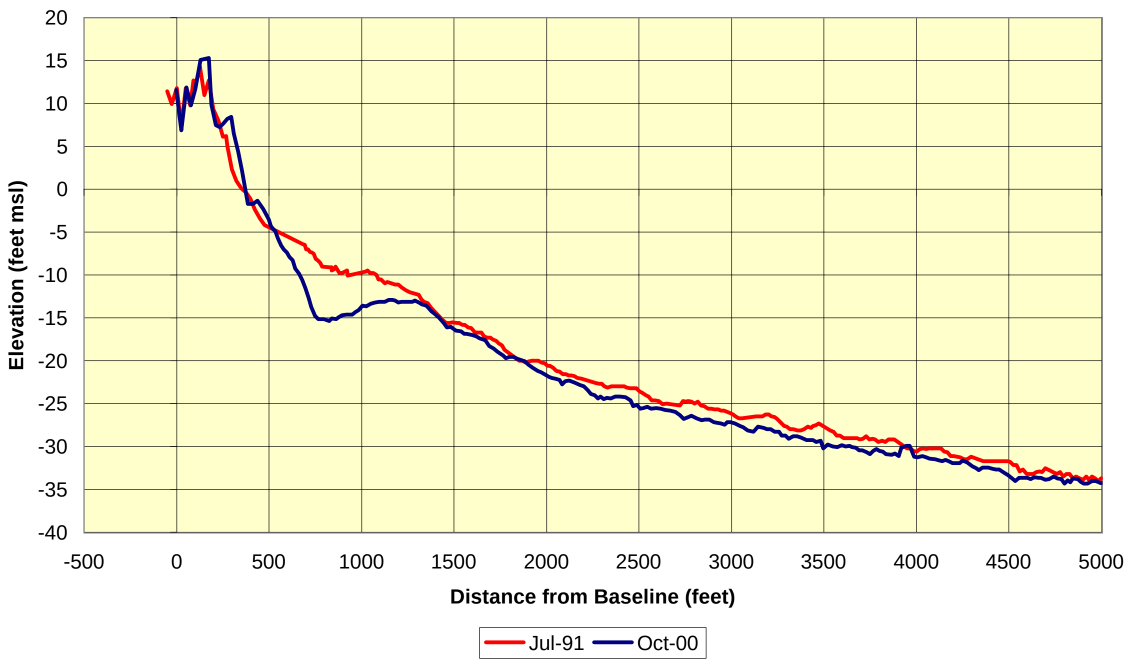


Figure A-27 Shackleford Banks Station 383+92
July 1991 & October 2000

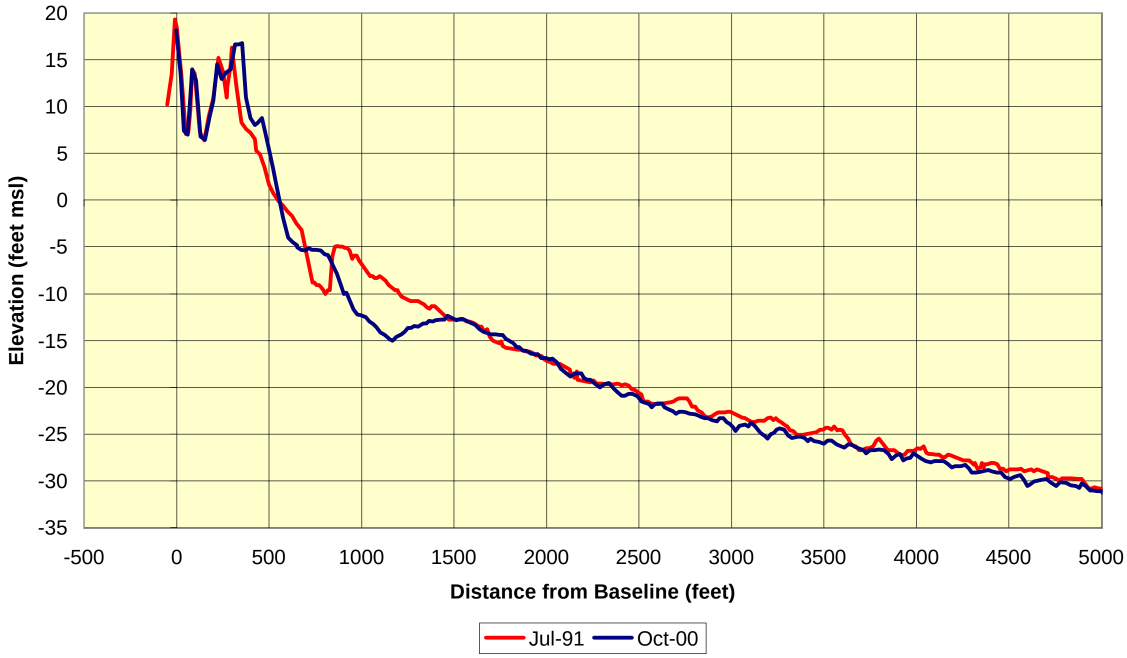


Figure A-28 Shackleford Banks Station 444+93
July 1991 & October 2000

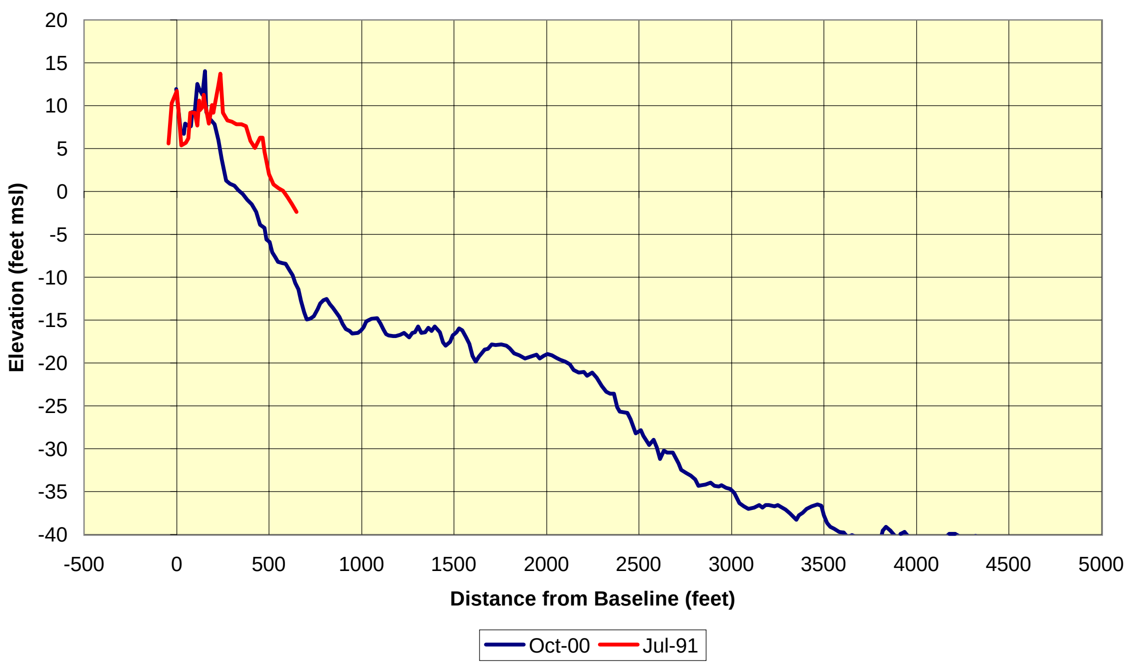


Figure A-47 Bogue Banks Station 32+68 June 1978
Station 32+64, April 2001
(Fort Macon)

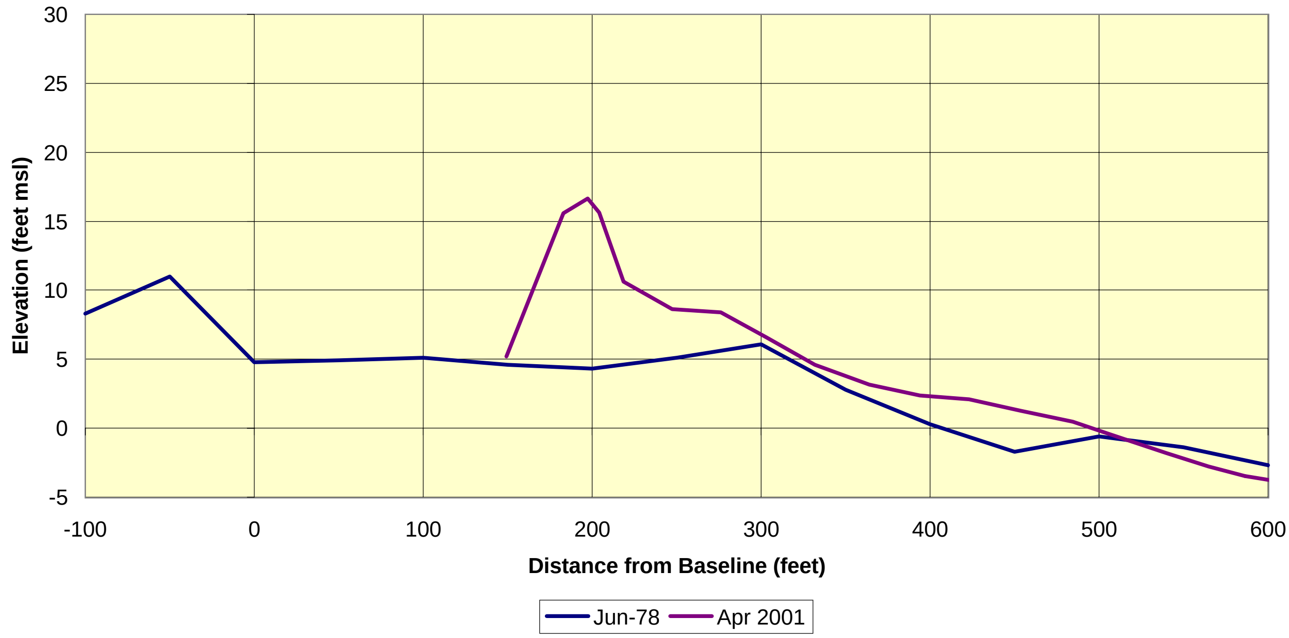


Figure A-48 Bogue Banks Station 40+00, June 1978
Station 43+10, April 2001
(Fort Macon)

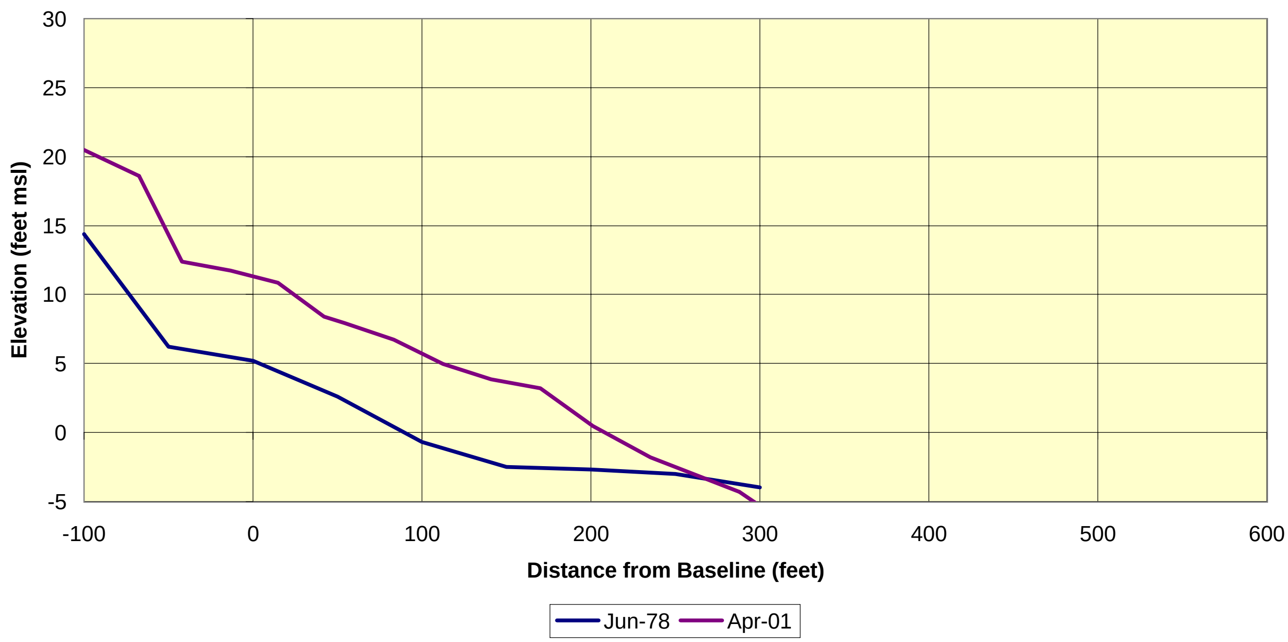


**Figure A-49 Bogue Banks Station 50+00, June 1978
Station 53+02, April 2001
(Fort Macon)**

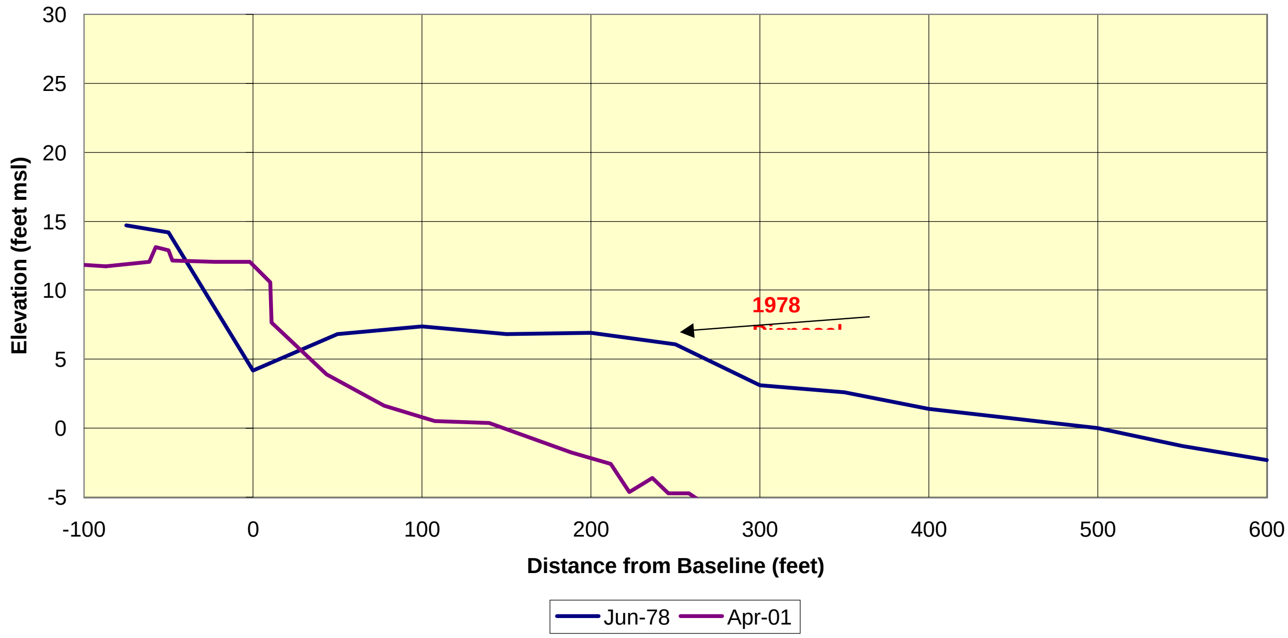


**Figure A-50 Bogue Banks Station 60+00, June 1978
Station 63+15, April 2001
(Fort Macon)**

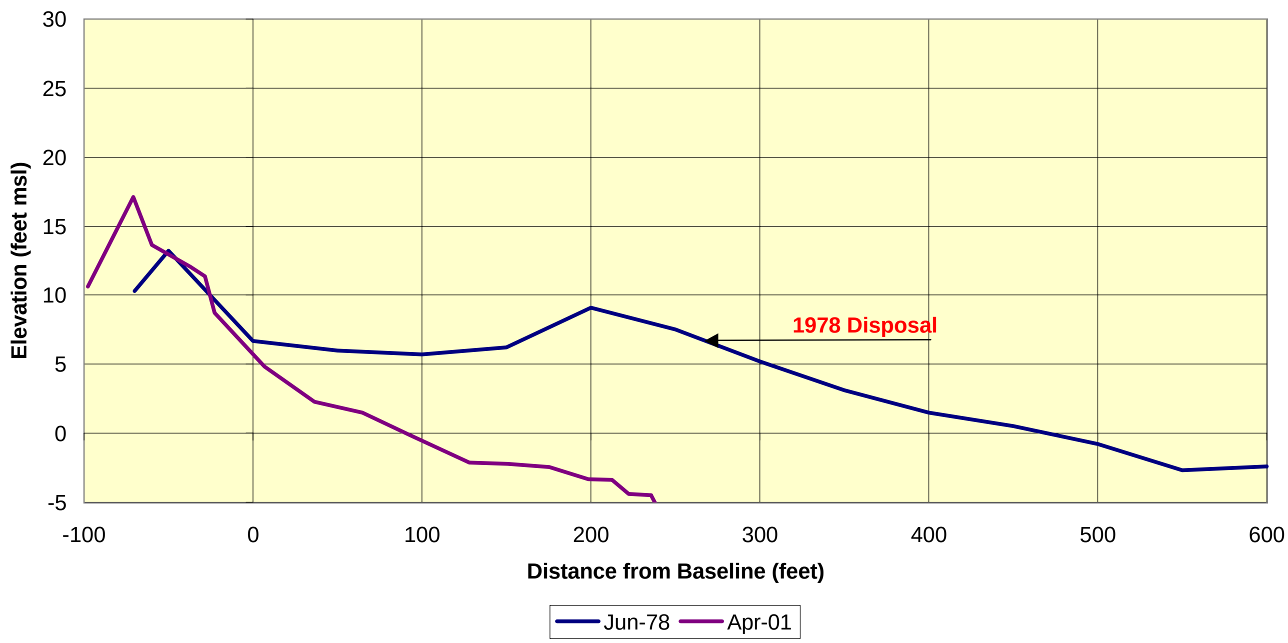


Figure A-51 Bogue Banks Station 70+00, June 1978
Station 73+07, April 2001
(Fort Macon)

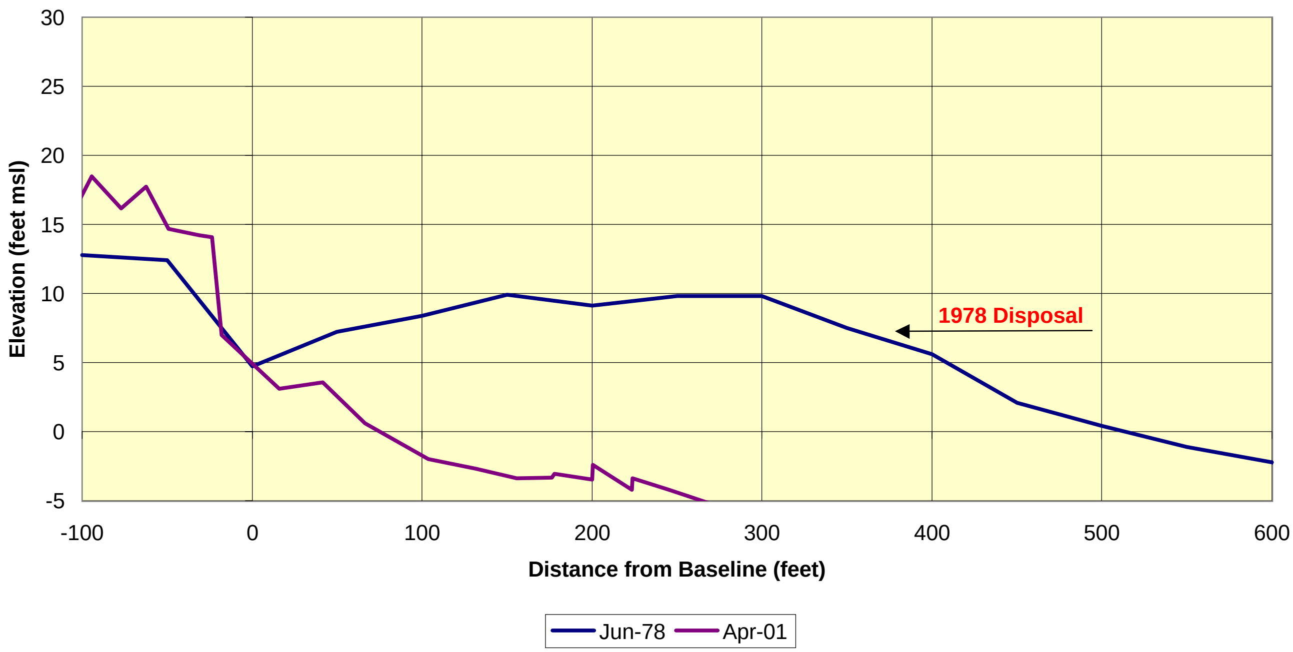


Figure A-52 Bogue Banks Station 80+00, June 1978
Station 83+16, April 2001
(Fort Macon)

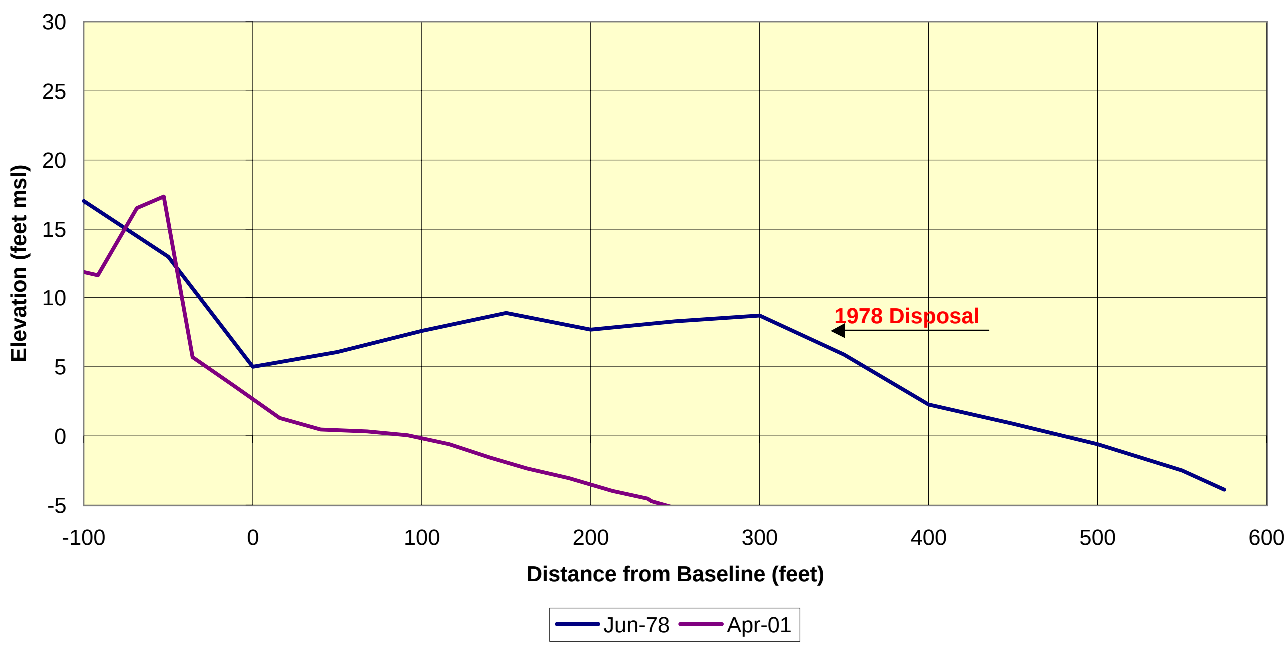


Figure A-53 Bogue Banks Station 90+00, June 1978
Station 93+33, April 2001
(Fort Macon)

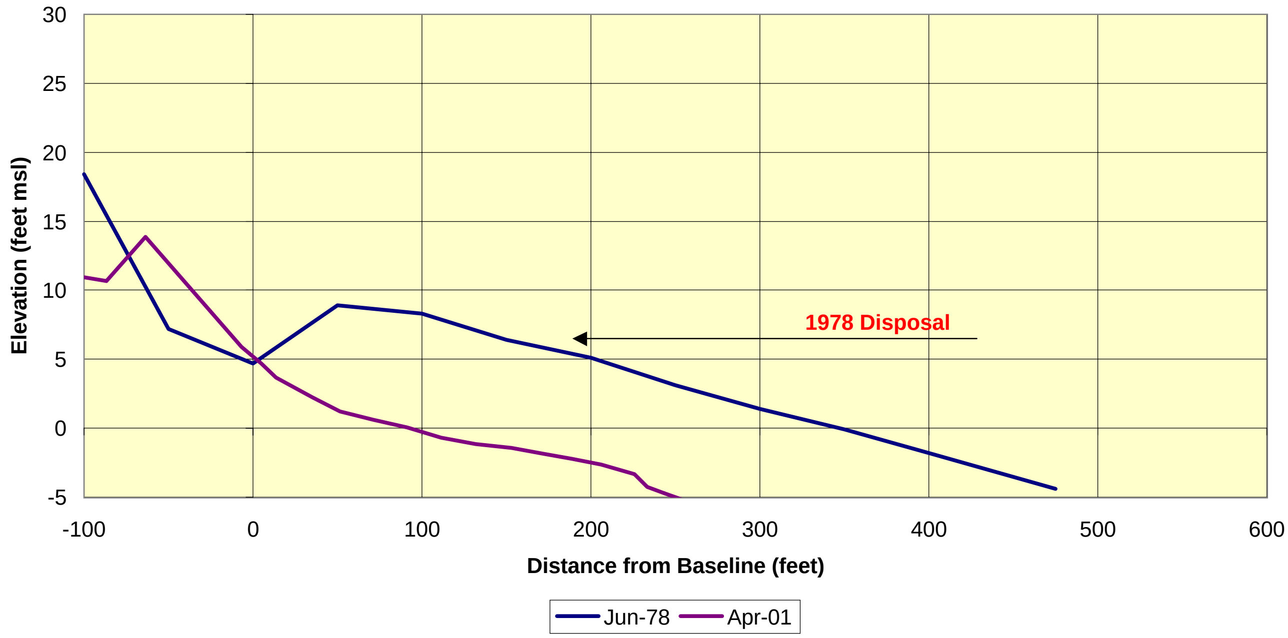


Figure A-54 Bogue Banks Station 100+00, June 1978
Station 103+43, April 2001
(Fort Macon-Atlantic Beach)

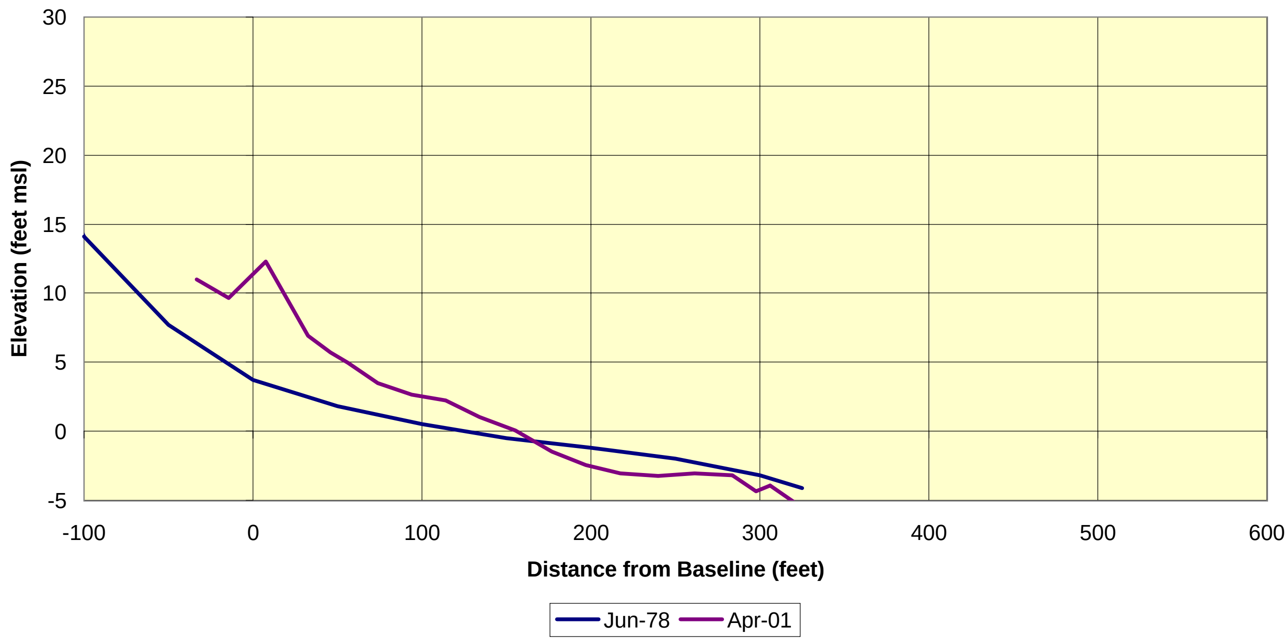


Figure A-55 Bogue Banks Station 120+00, June 1978
Station 123+36, April 2001
(Atlantic Beach)

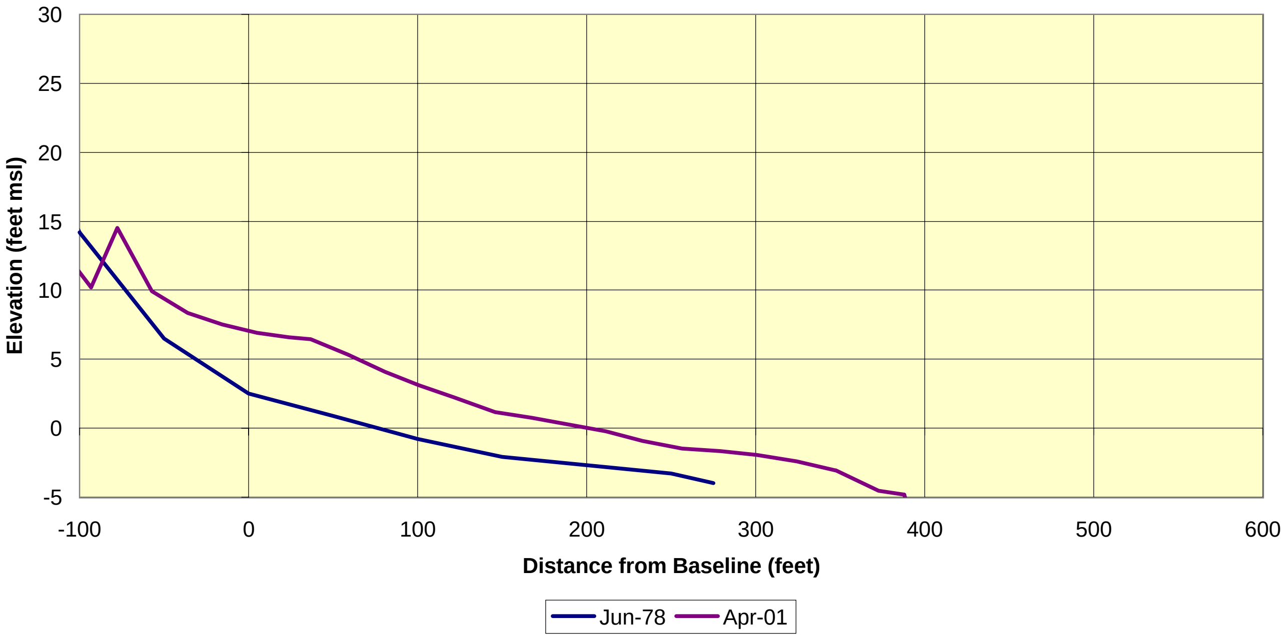


Figure A-56 Bogue Banks Station 140+00, June 1978
Station 143+37, April 2001
(Atlantic Beach)

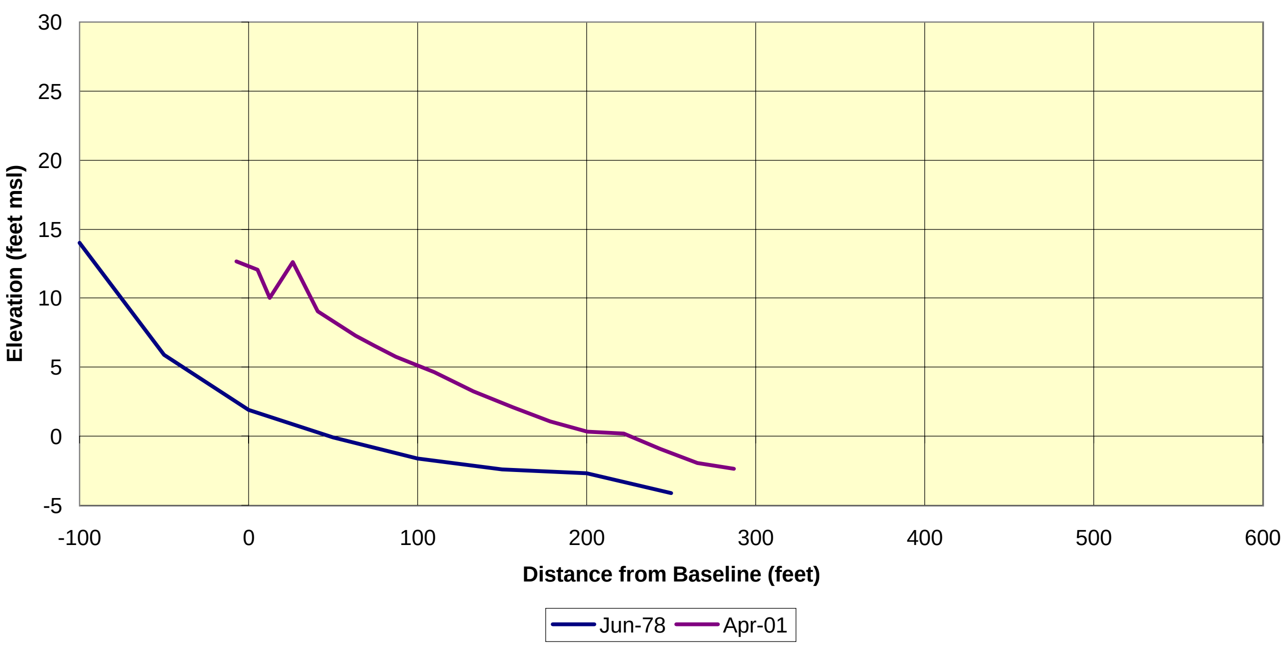


Figure A-57 Bogue Banks Station 160+00, June 1978
Station 163+40, April 2001
(Atlantic Beach)

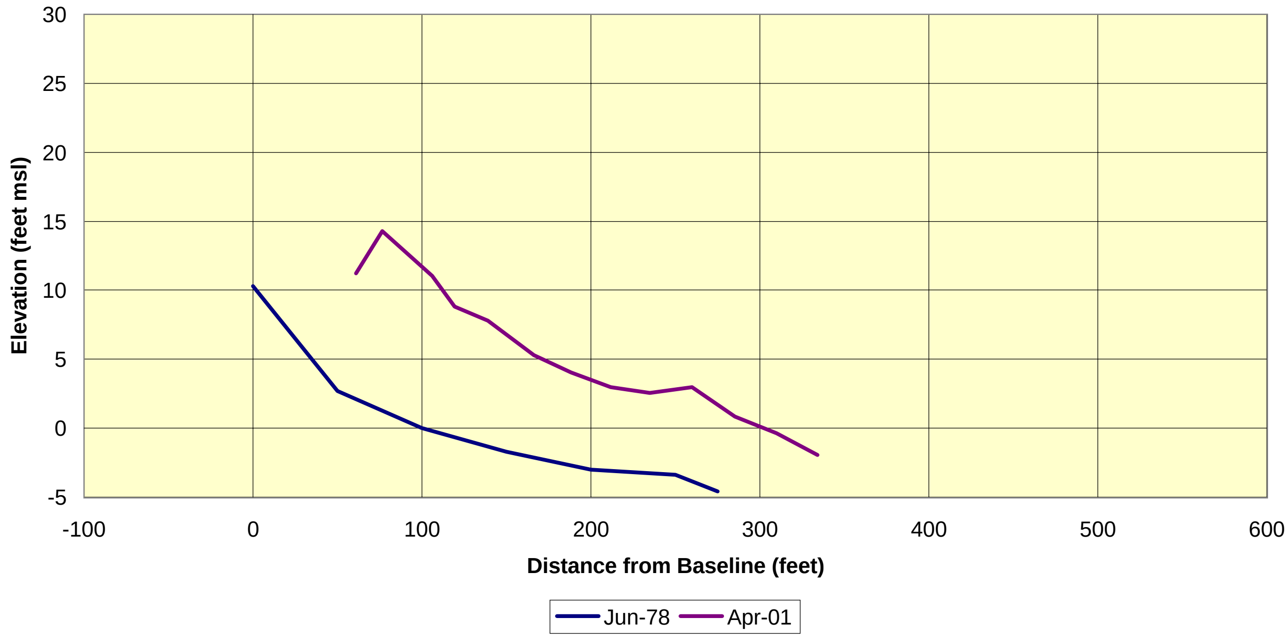


Figure A-58 Bogue Banks Station 181+00, June 1978
Station 183+36, April 2001
(Atlantic Beach)

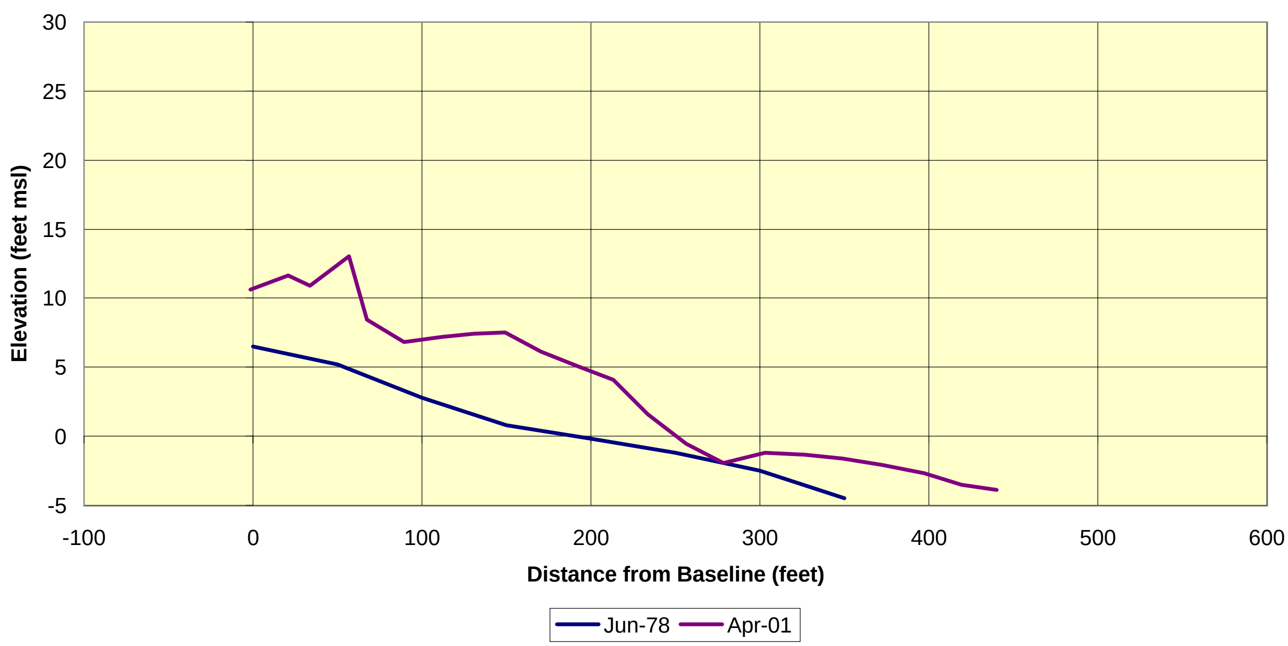


Figure A-59 Bogue Banks Station 200+00, June 1978
Station 203+38, June 2001
(Atlantic Beach)

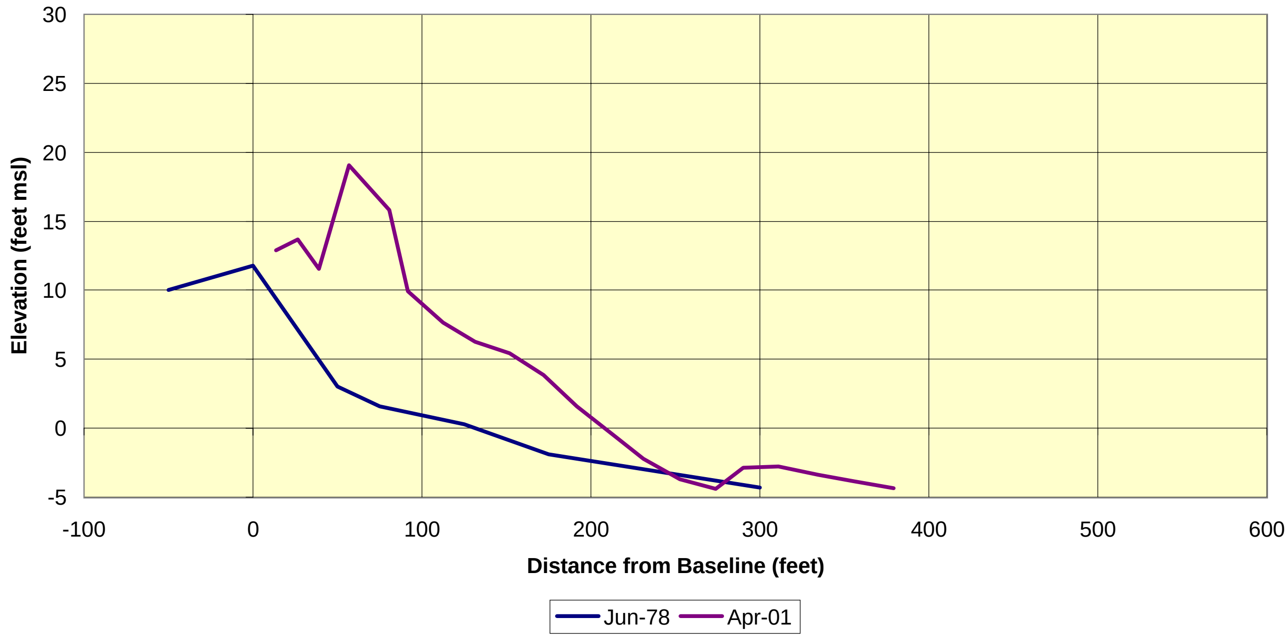


Figure A-60 Bogue Banks Station 220+00, June 1978
Station 223+28, April 2001
(Atlantic Beach)

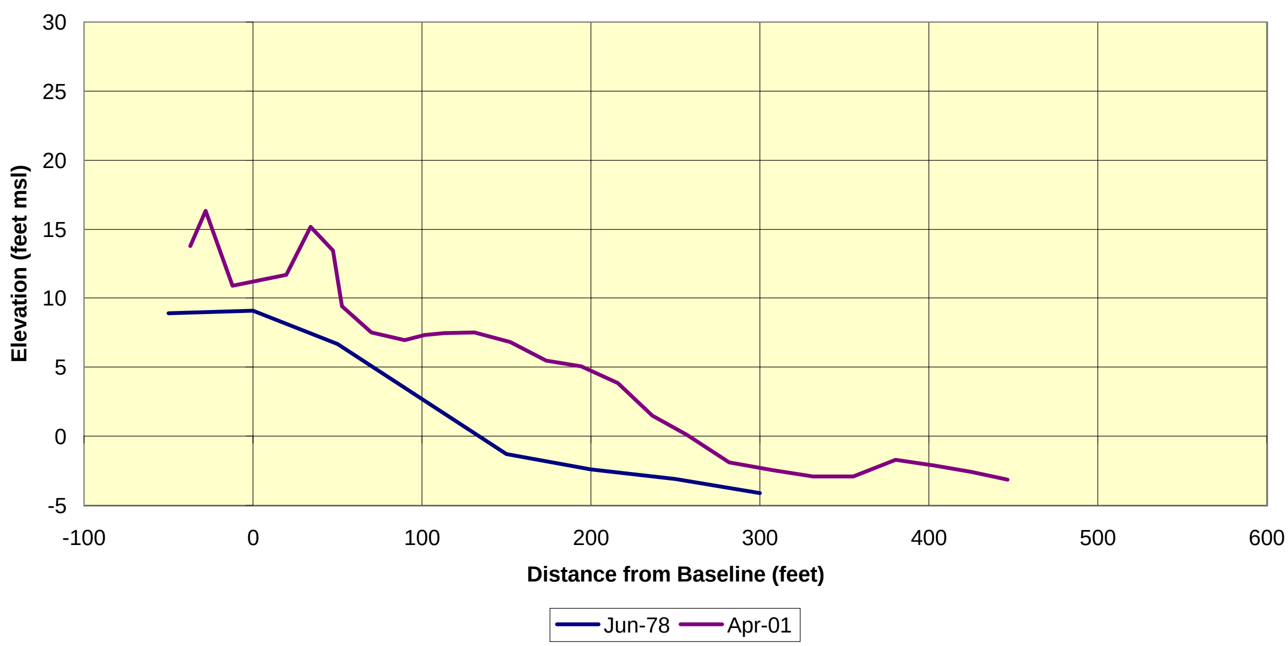


**Figure A-61 Bogue Banks Station 240+00, June 1978
Station 243+29, April 2001
(Atlantic Beach)**

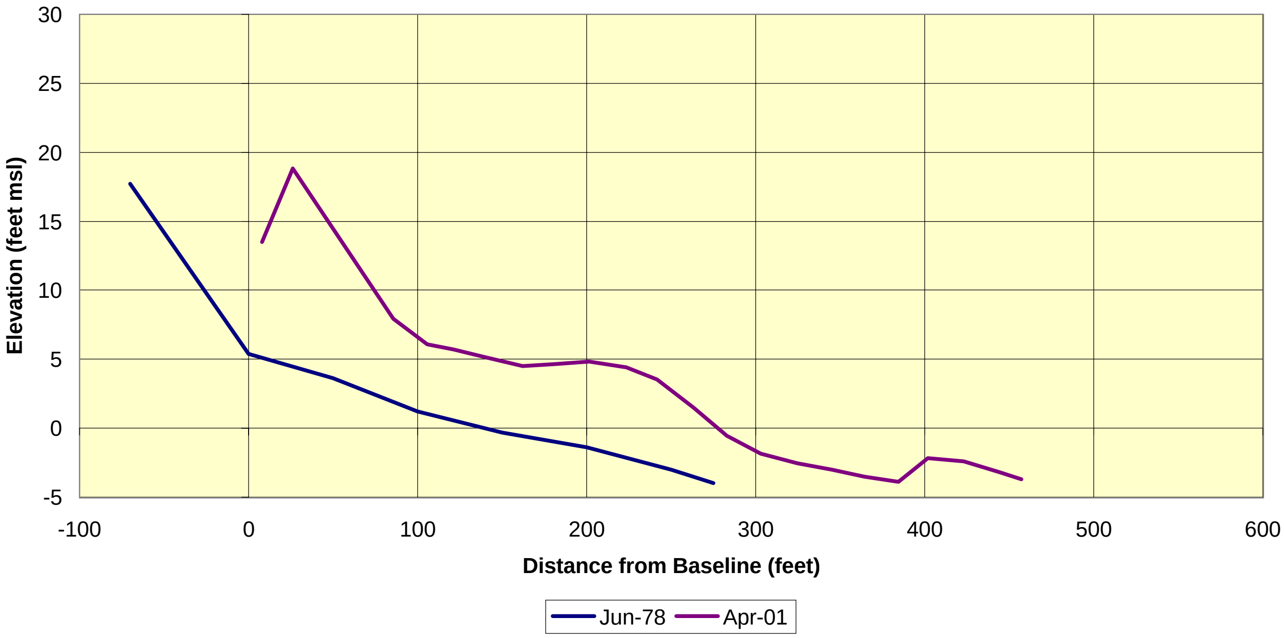


**Figure A-62 Bogue Banks Station 260+00, June 1978
Station 263+24, April 2001
(Atlantic Beach)**

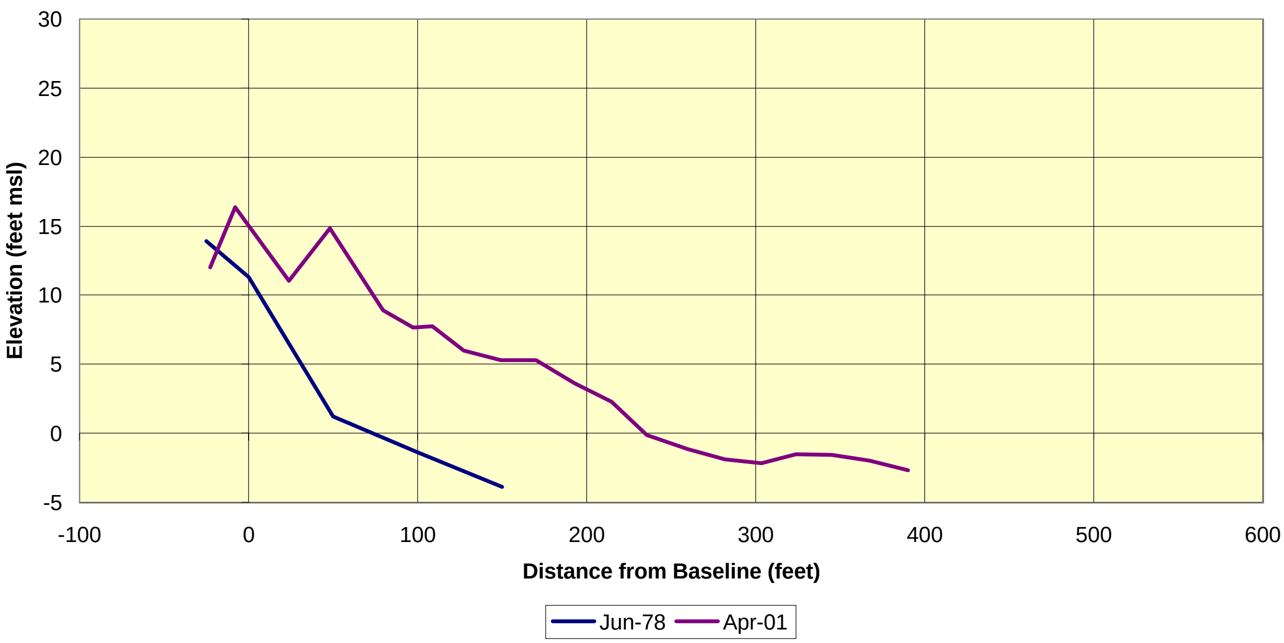


Figure A-63 Bogue Banks Station 280+00, June 1978
Station 283+26, April 2001
(Atlantic Beach)

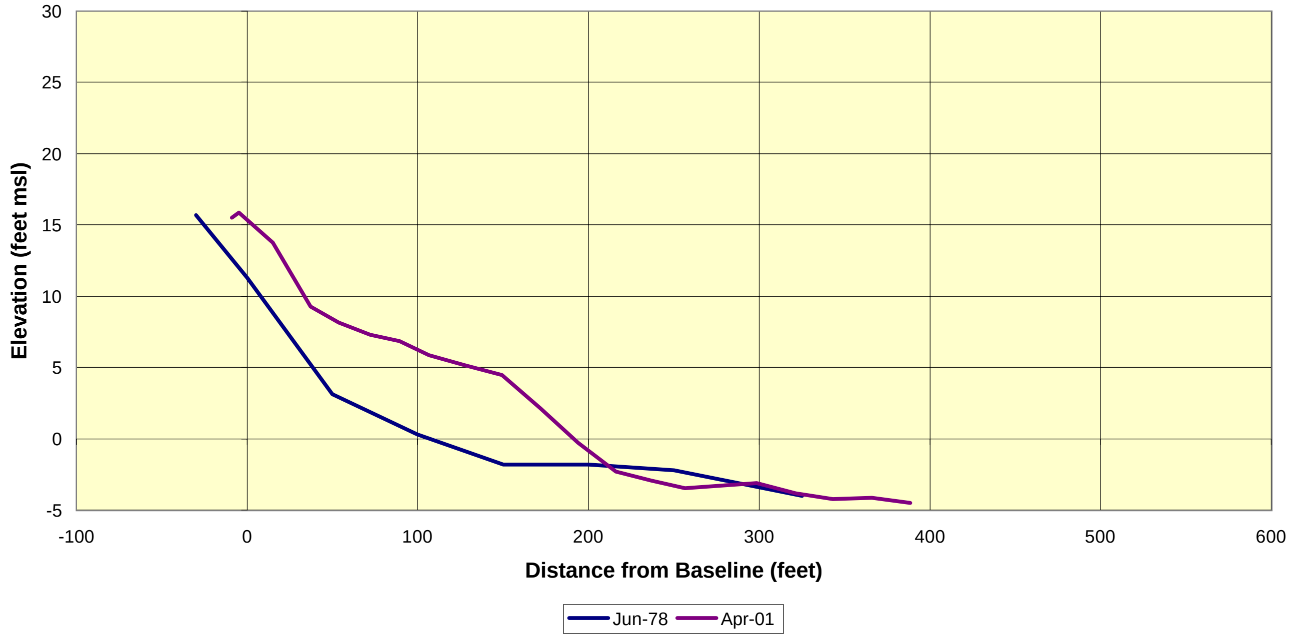
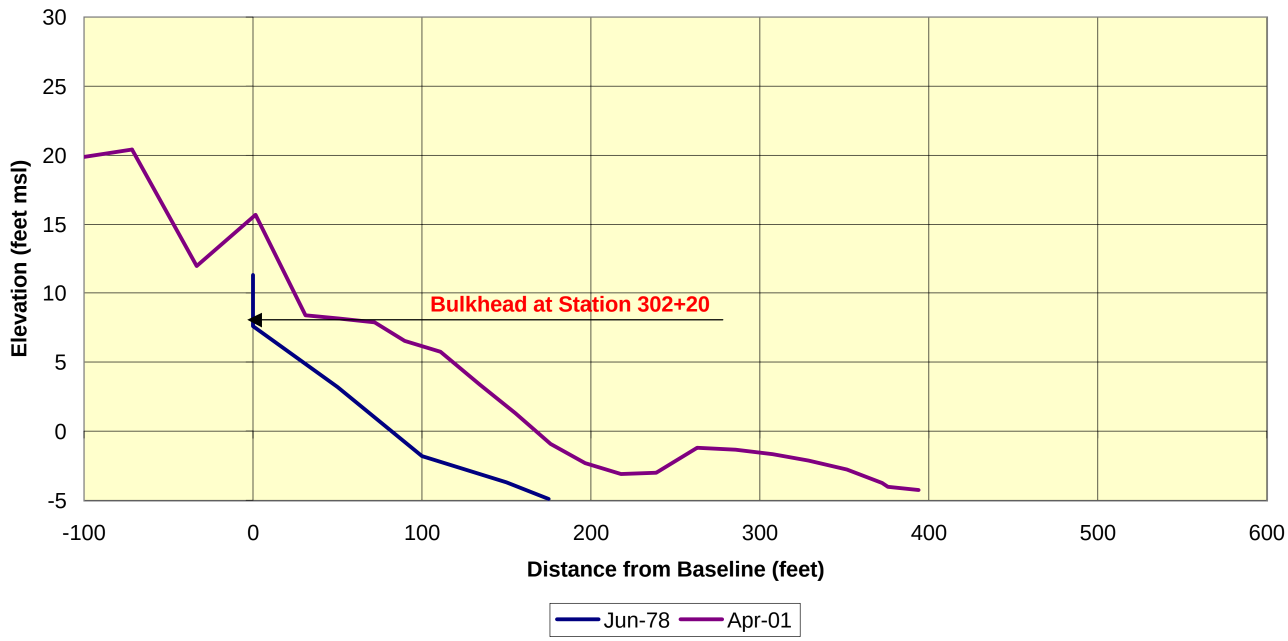


Figure A-64 Bogue Banks Station 303+20, June 1978
Station 303+26, April 2001
(Atlantic Beach)



Appendix A x-section plots 2.xls
280 and 300

Figure A-65 Bogue Banks Station 318+00, June 1978
Station 323+60, April 2001
(Atlantic Beach & Pine Knoll Shores)

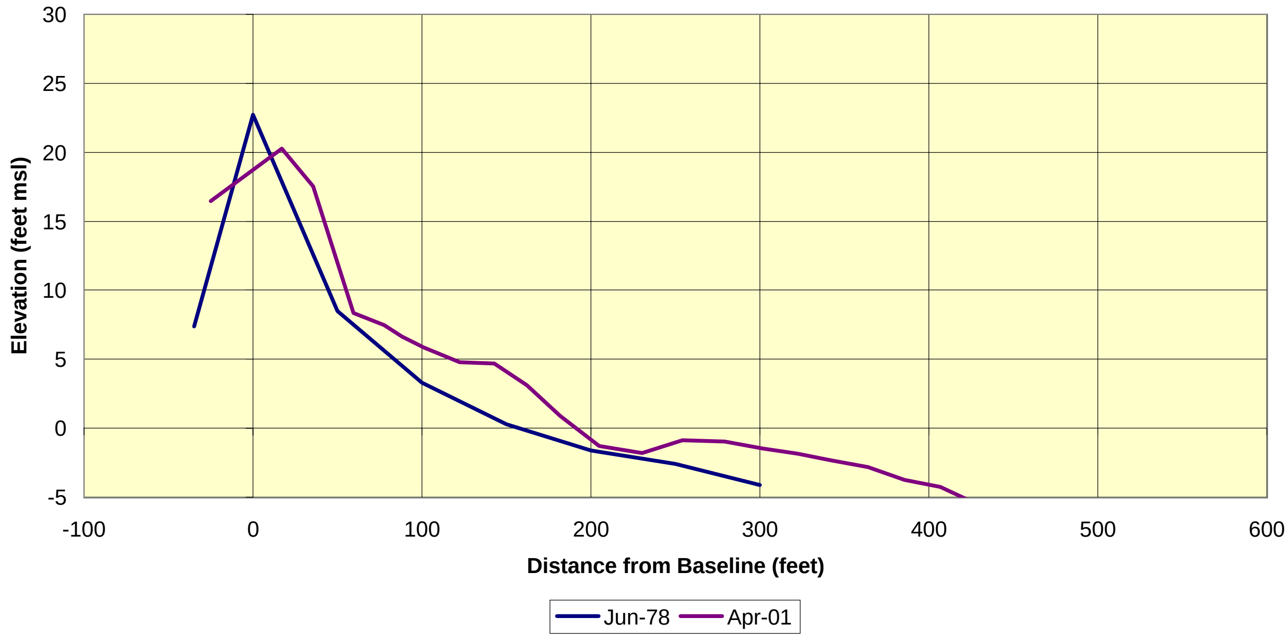


Figure A-66 Bogue Banks Station 341+51, June 1978
Station 342+72, April 2001
(Pine Knoll Shores)

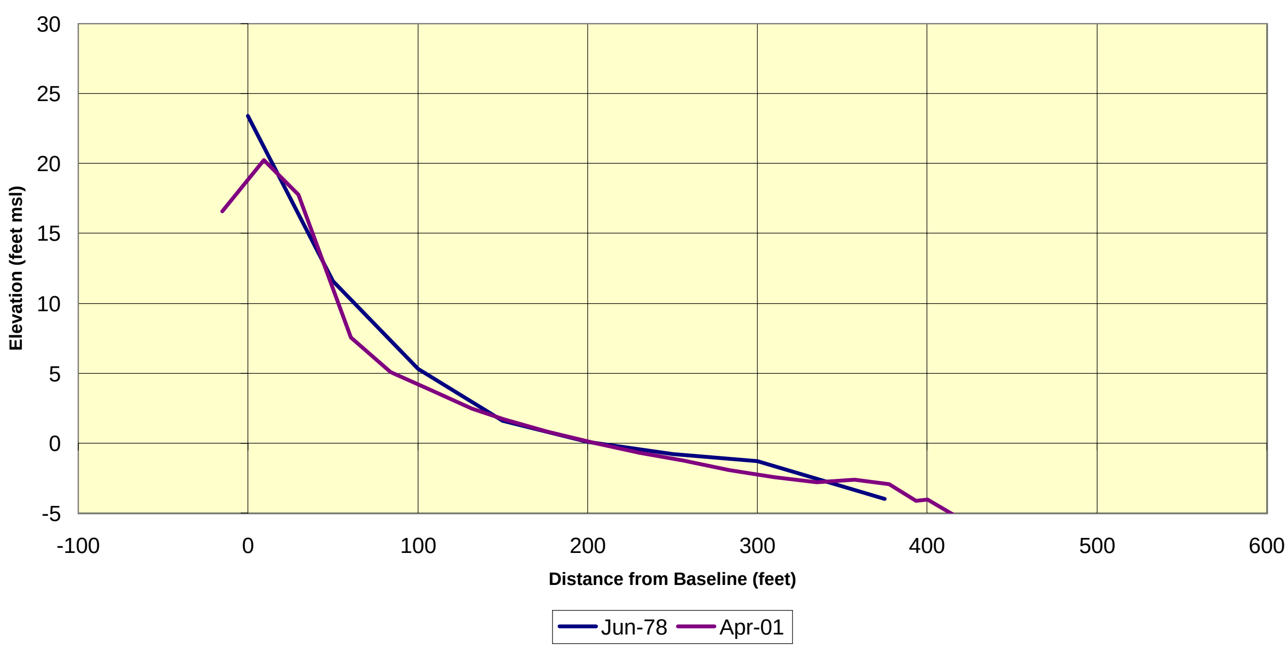


Figure A-67 Bogue Banks Station 357+87, June 1978
Station 353+12, April 2001
(Pine Knoll Shores)

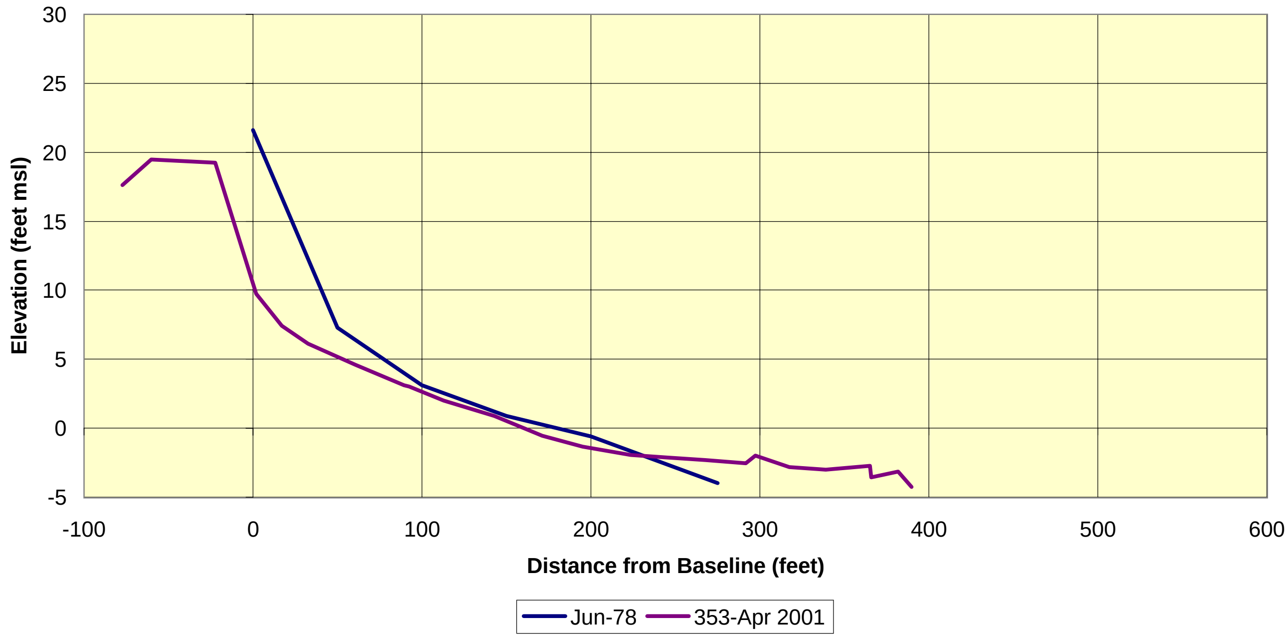


Figure A-68 Bogue Banks Station 379+59, June 1978
Station 383+08, April 2001
(Pine Knoll Shores)

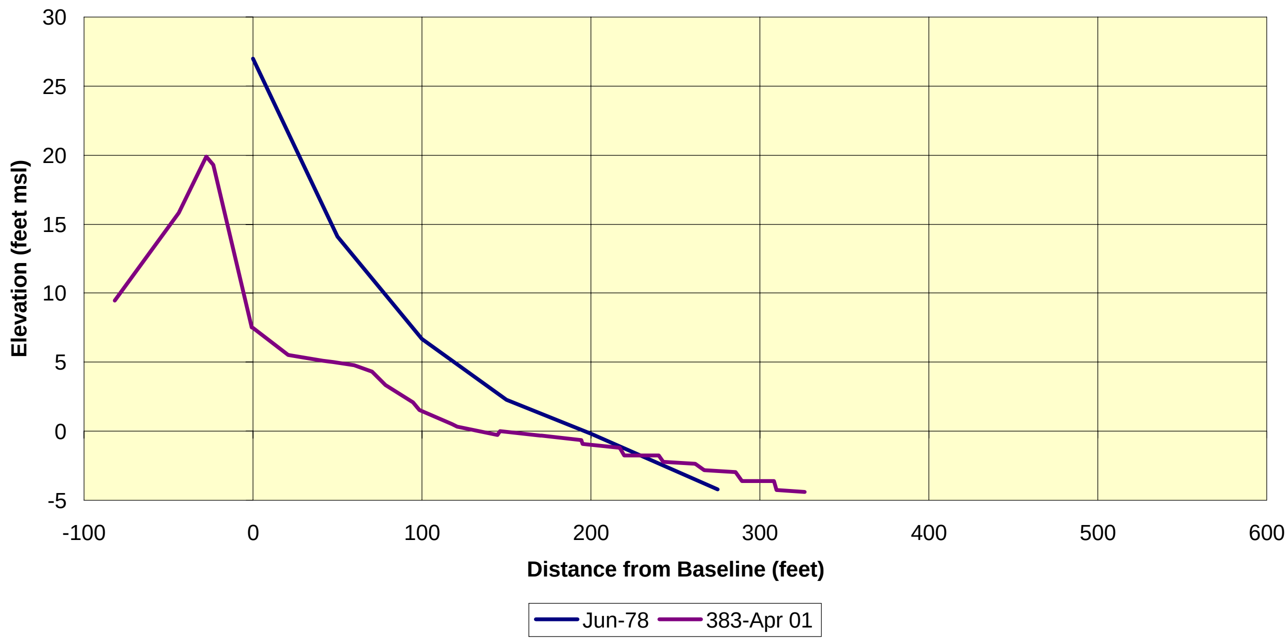


Figure A-69 Bogue Banks Station 403+85, June 1978
Station 403+07, April 2001
(Pine Knoll Shores)

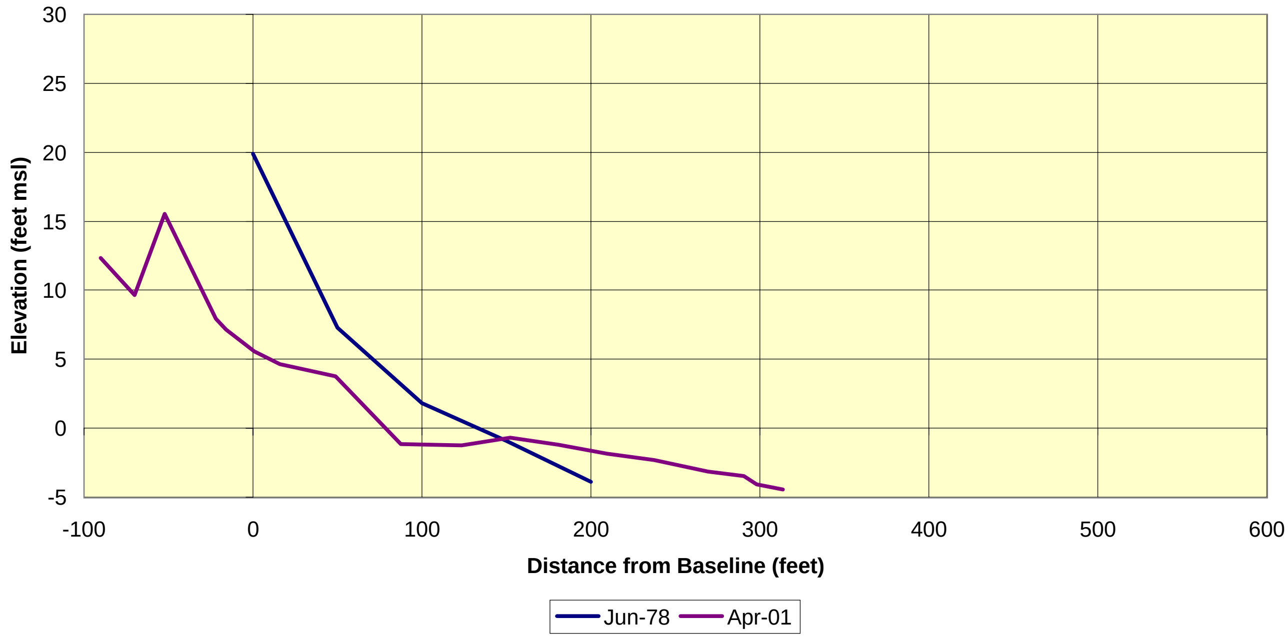


Figure A-70 Bogue Banks Station 429+18, June 1978
Station 433+05, April 2001
(Pine Knoll Shores)

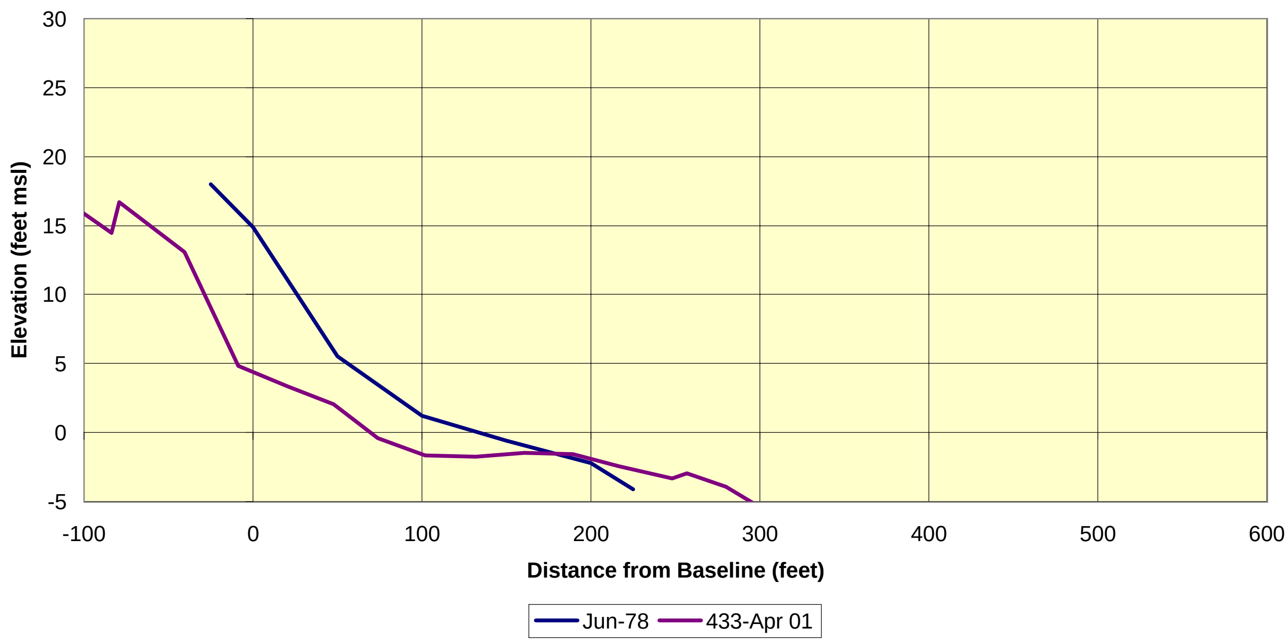


Figure A-71 Bogue Banks Station 449+96, June 1978
Station 453+05, April 2001
(Pine Knoll Shores)

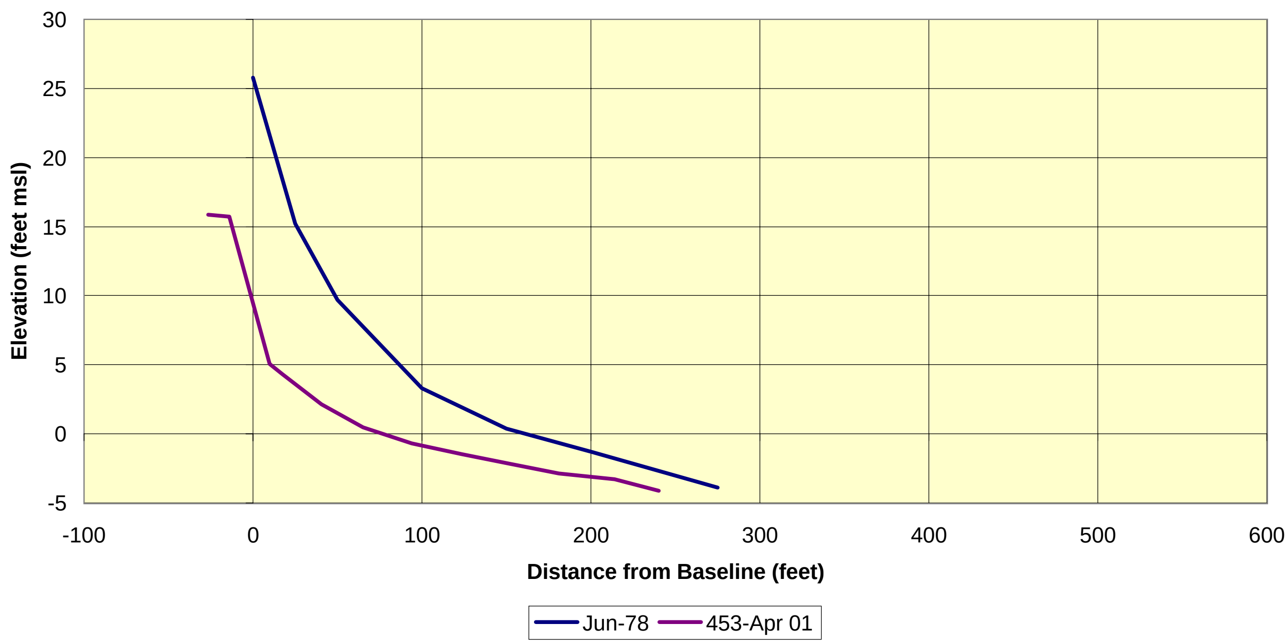


Figure A-72 Bogue Banks Station 484+58, June 1978
Station 482+83, April 2001
(Pine Knoll Shores)

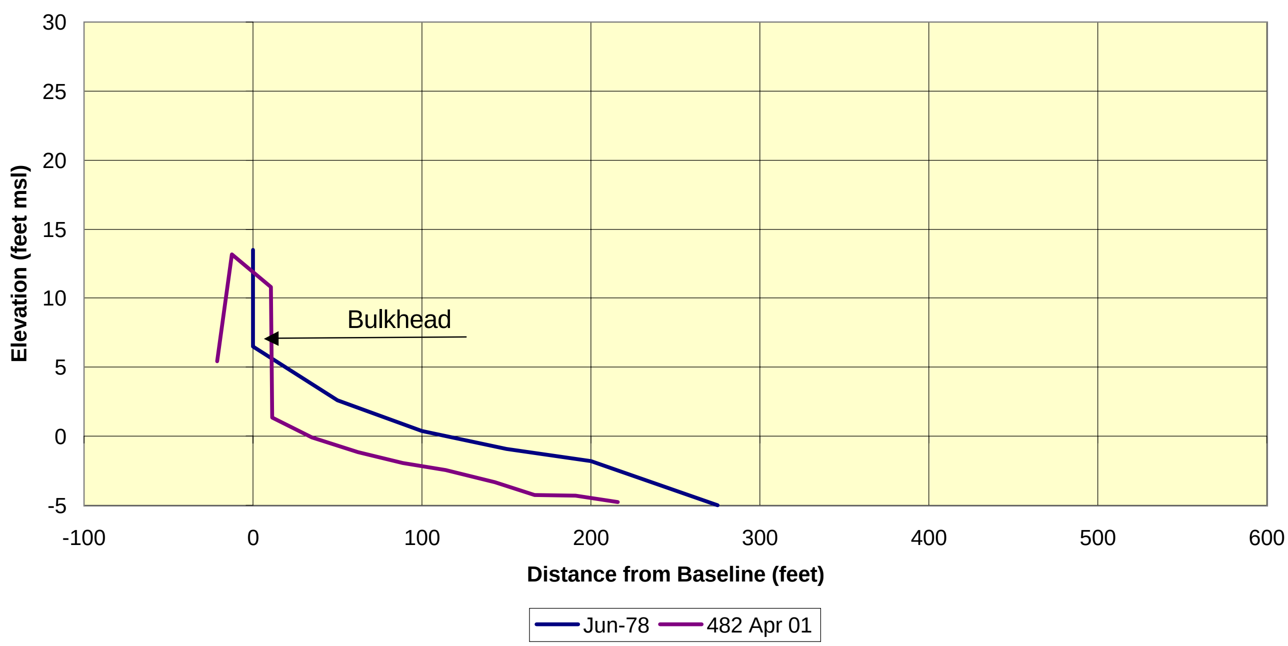


Figure A-73 Bogue Banks Station 503+54, June 1978
Station 503+04, April 2001
(Pine Knoll Shores)

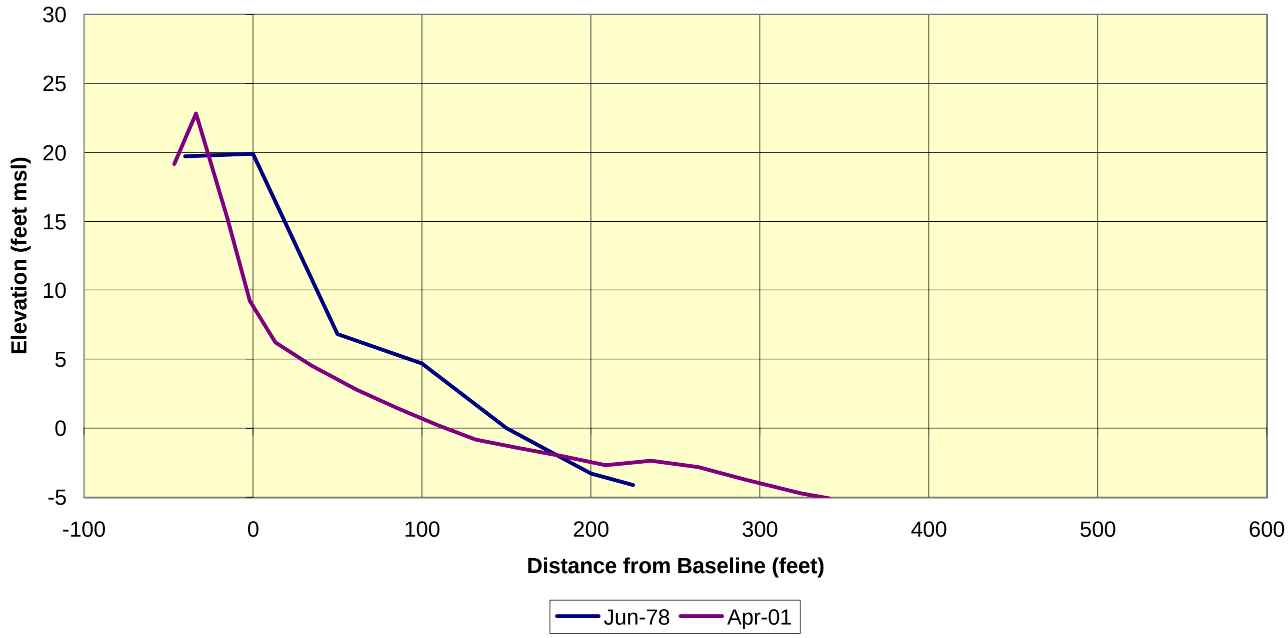


Figure A-74 Bogue Banks Station 532+10, June 1978
Station 533+00, April 2001
(Pine Knoll Shores)

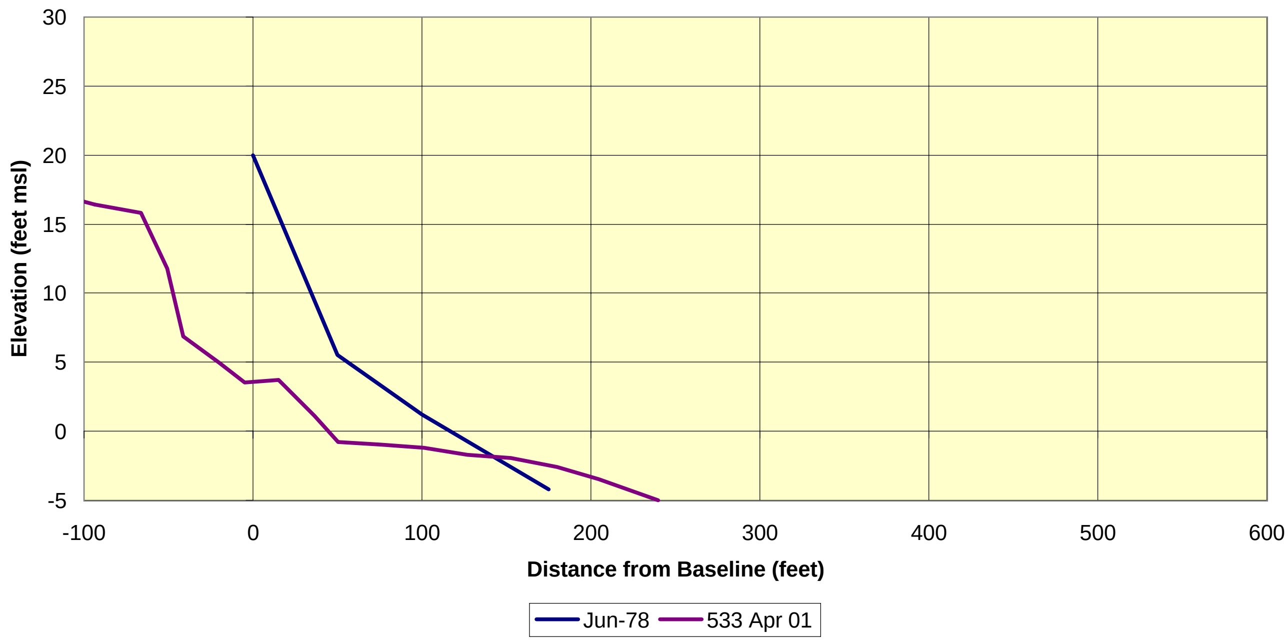


**Figure A-75 Bogue Banks Station 549+40, June 1978
Station 552+99, April 2001
(Pine Knoll Shores)**

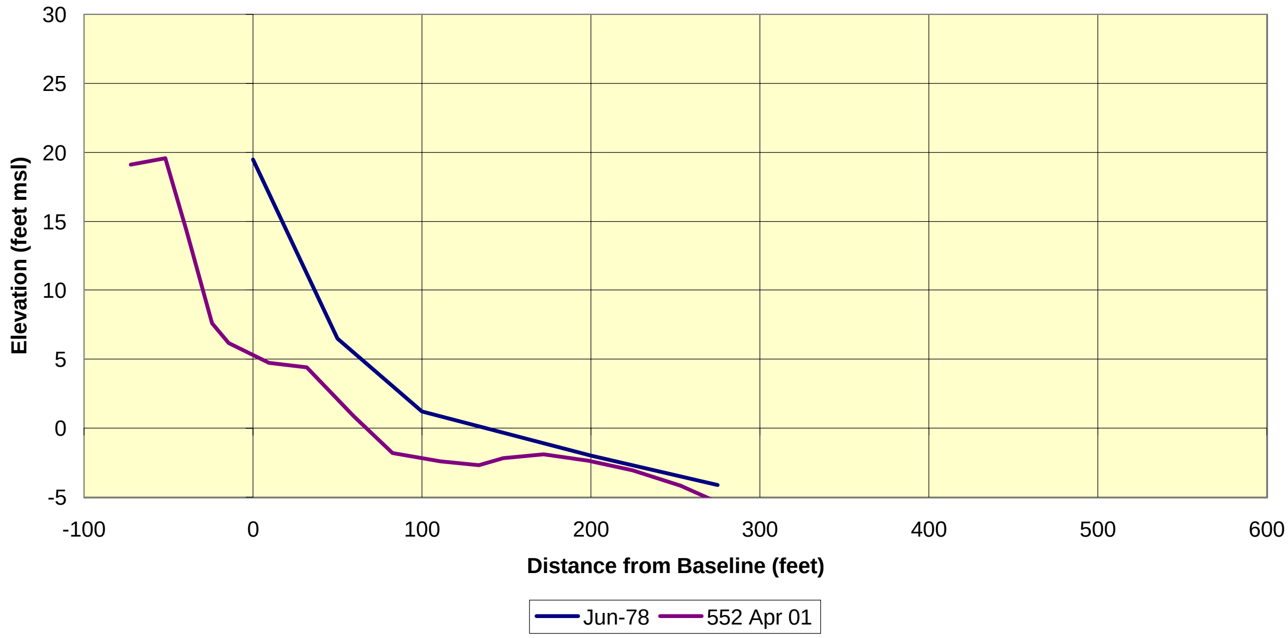


**Figure A-76 Bogue Banks Station 568+05, June 1978
Station 573+23, April 2001
(Indian Beach)**

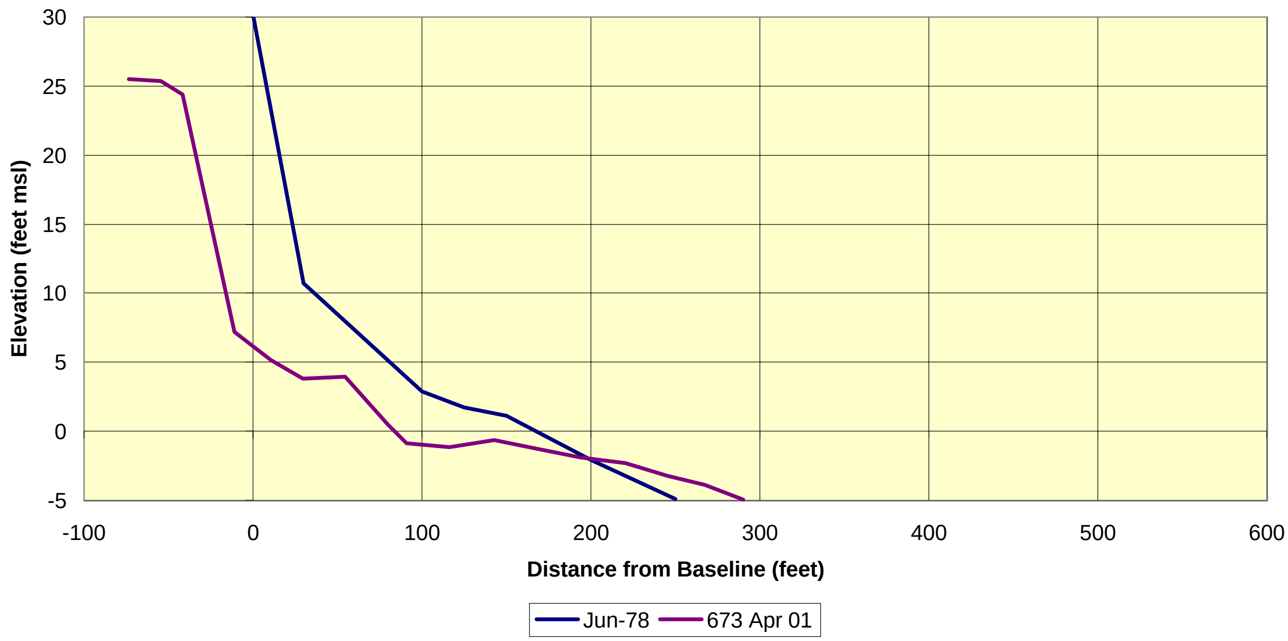


Figure A-77 Bogue Banks Station 589+46, June 1978
Station 592+96, April 2001
(Indian Beach)

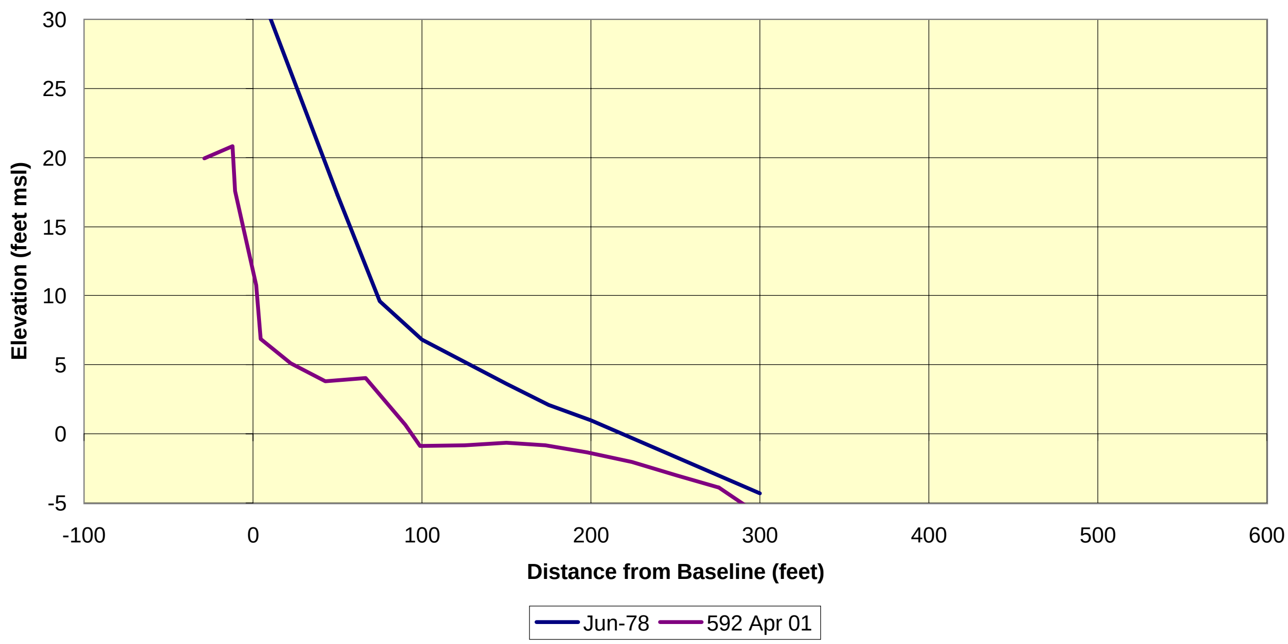


Figure A-78 Bogue Banks Station 614+89
Station 612+95, April 2001
(Indian Beach)

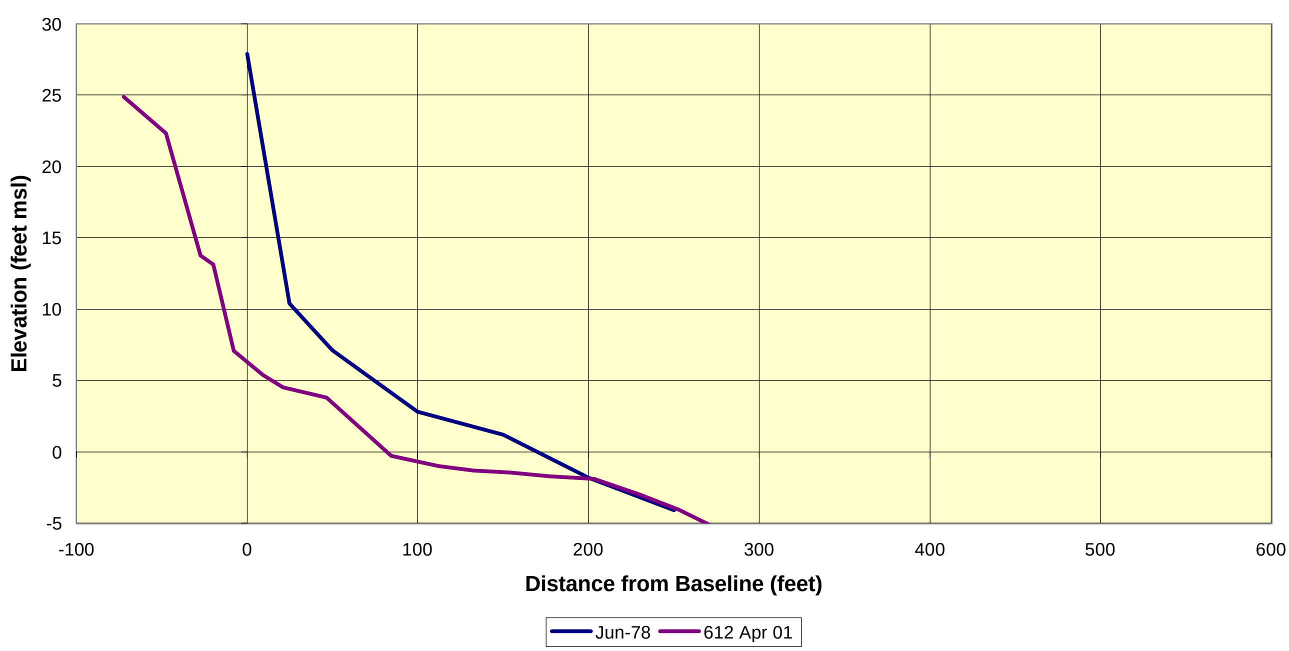


Figure A- 79 Bogue Banks Station 633+00, June 1978
Station 633+05, April 2001
(Indian Beach)

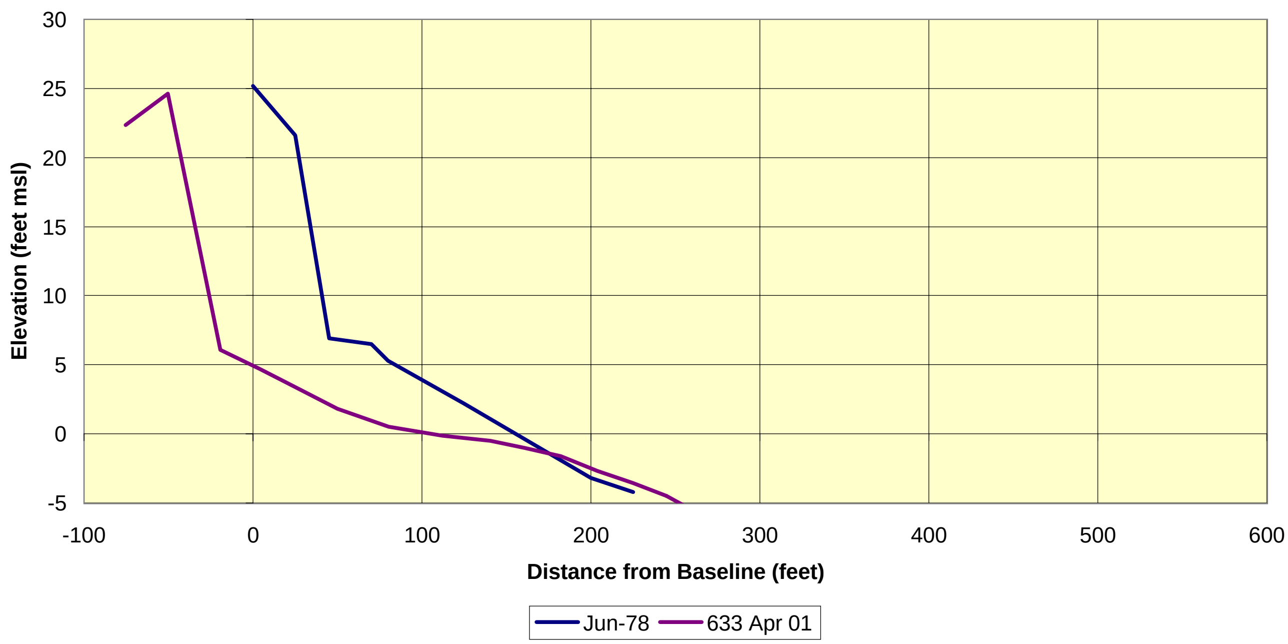


Figure A-80 Bogue Banks Station 655+15, June 1978
Station 653+41, April 2001
(Indian Beach)

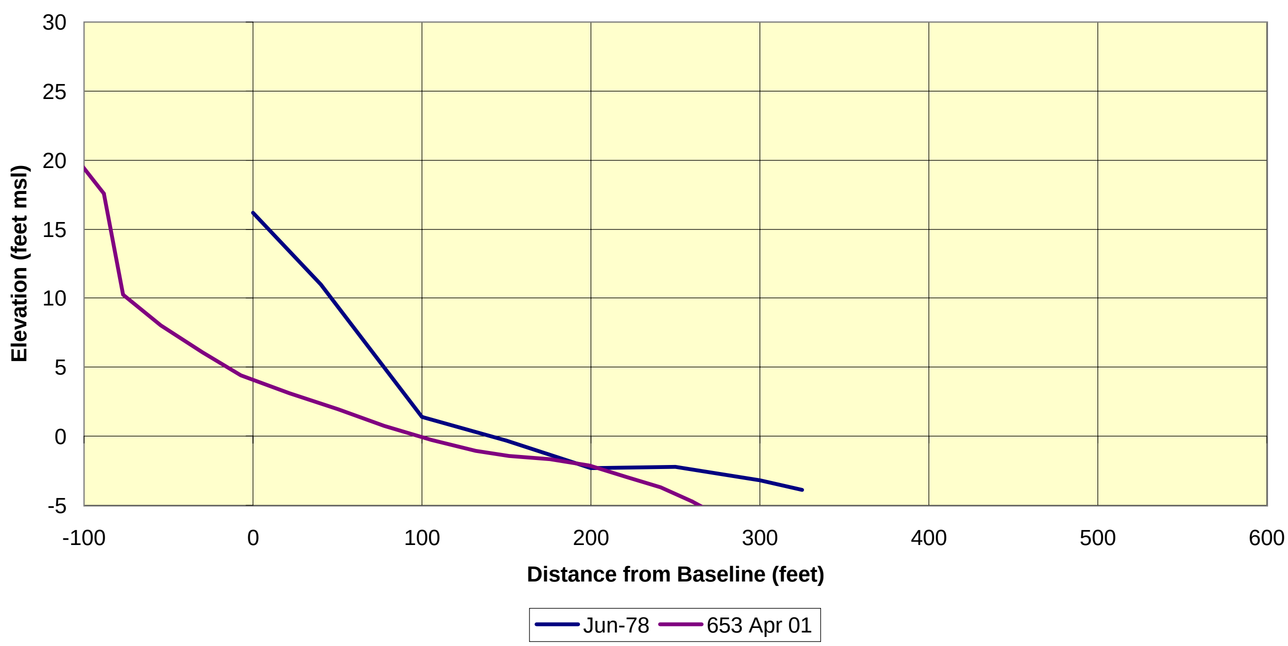


Figure A-81 Bogue Banks Station 674+31, June 1978
Station 672+73, April 2001
(Indian Beach)

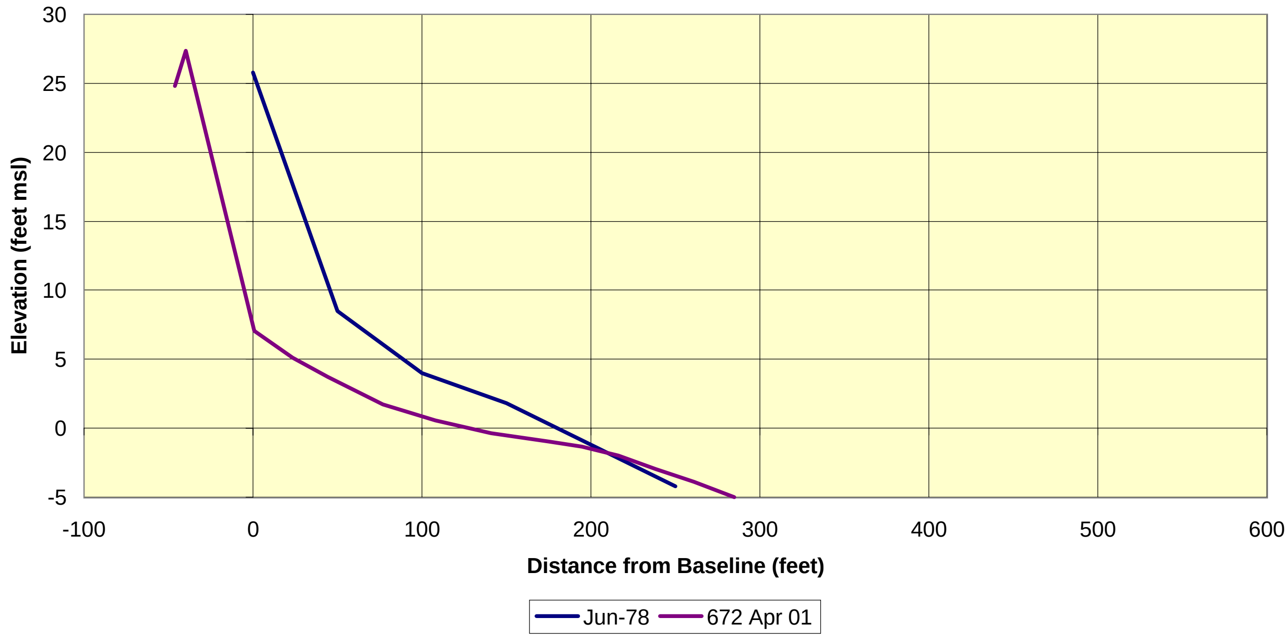


Figure A-82 Bogue Banks Station 693+64, June 1978
Station 692+48, April 2001
(Indian Beach)

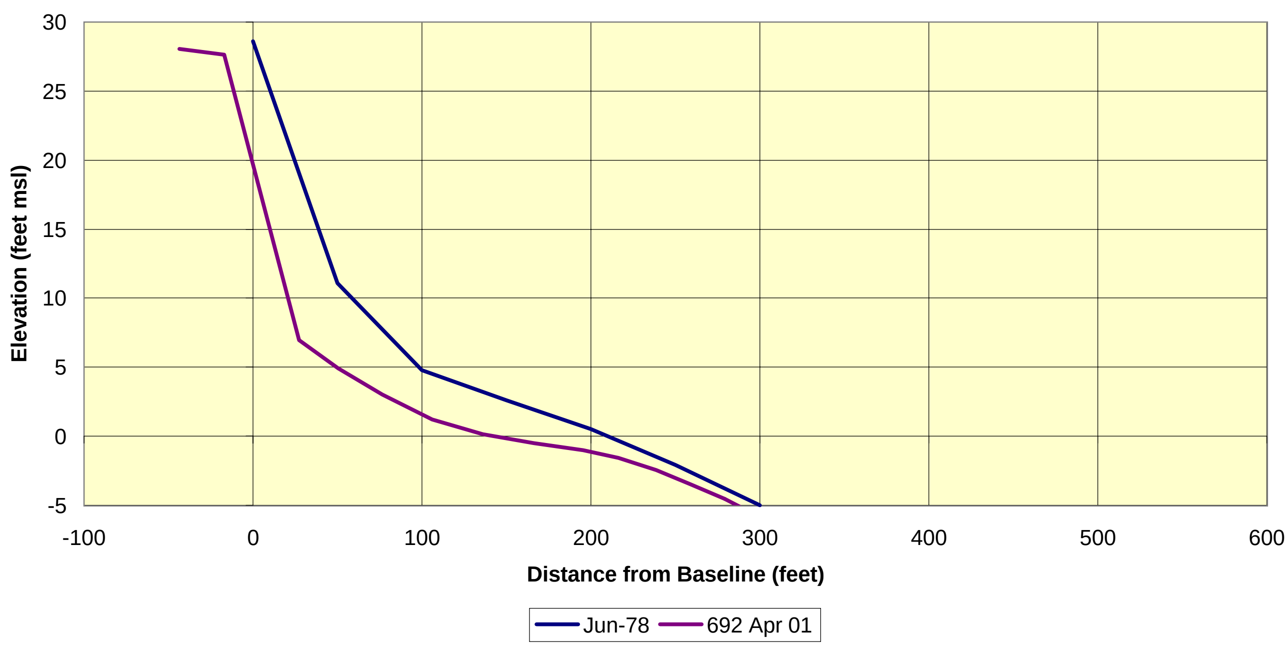


**Figure A-83 Bogue Banks Station 720+74, June 1978
Station 722+97, April 2001
(East Emerald Isle)**

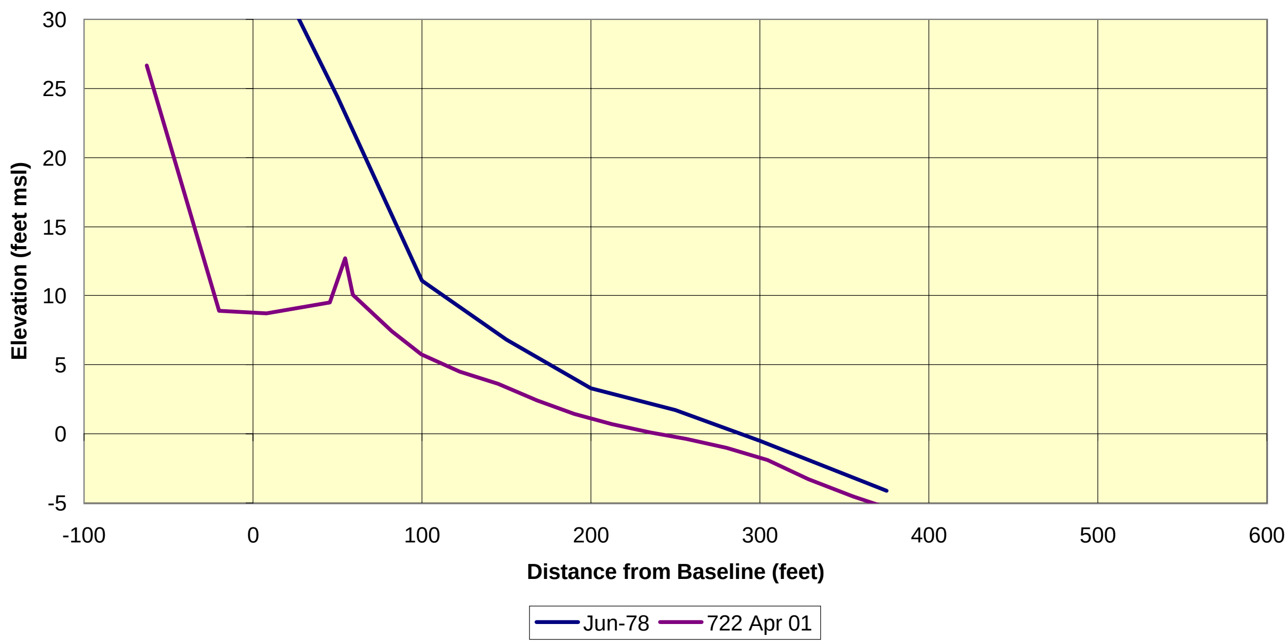


**Figure A-84 Bogue Banks Station 778+41, June 1978
Station 782+92, April 2001
(East Emerald Isle)**

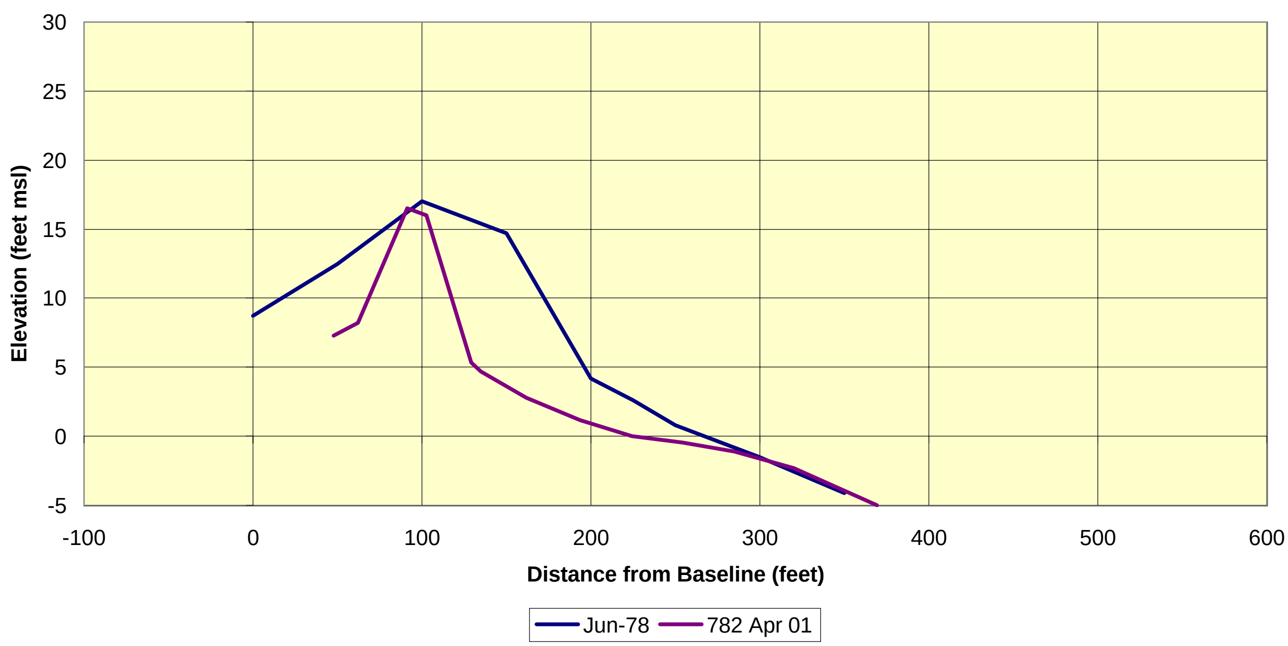


**Figure A-85 Bogue Banks Station 856+42, June 1978
Station 852+91, April 2001
(East Emerald Isle)**

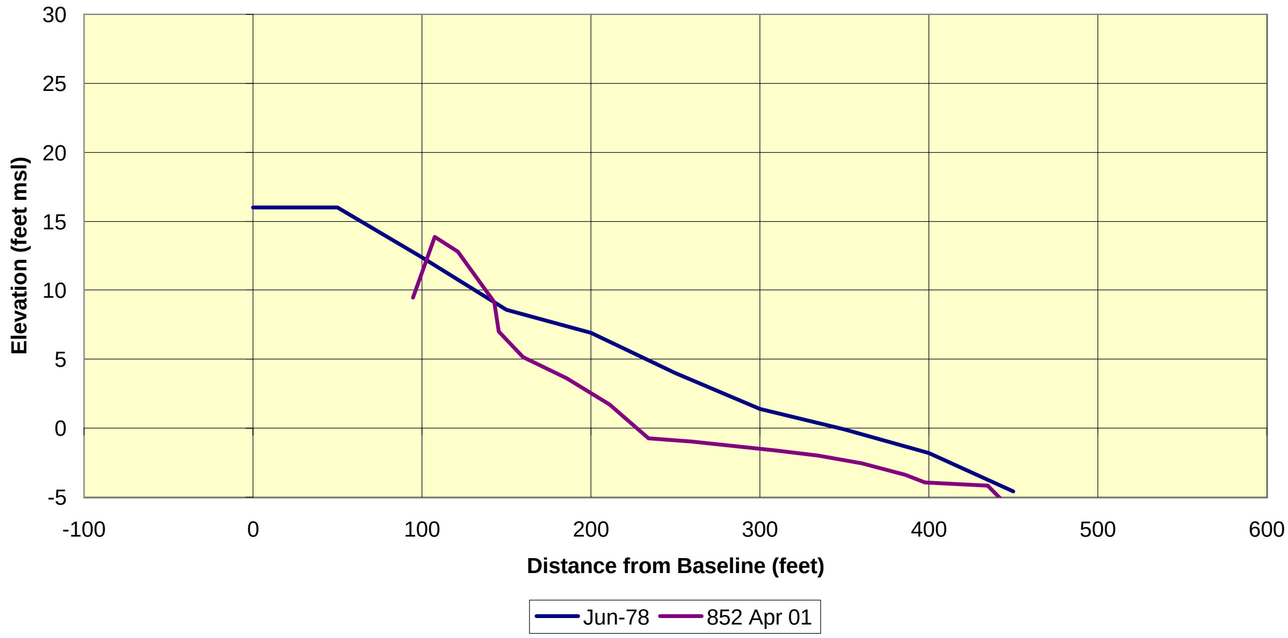


**Figure A-86 Bogue Banks Station 911+99, June 1978
Station 912+92, April 2001
(East Emerald Isle)**

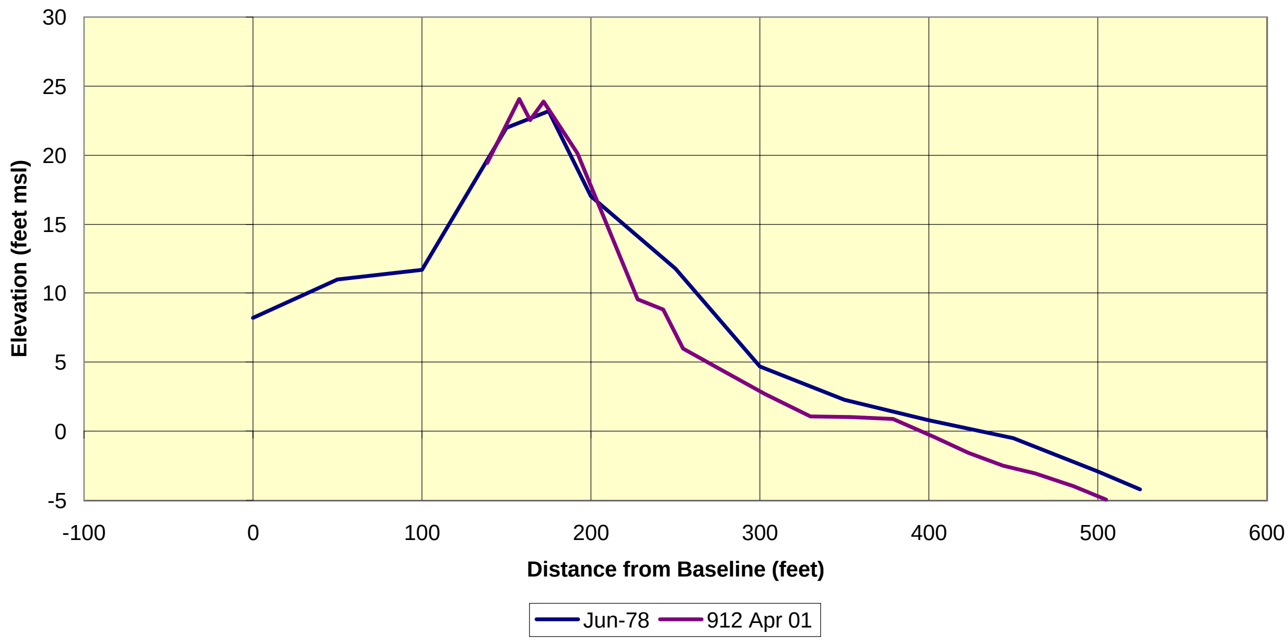


Figure A-87 Bogue Banks Station 939+44, June 1978 Station 943+55, April 2001 (West Emerald Isle)

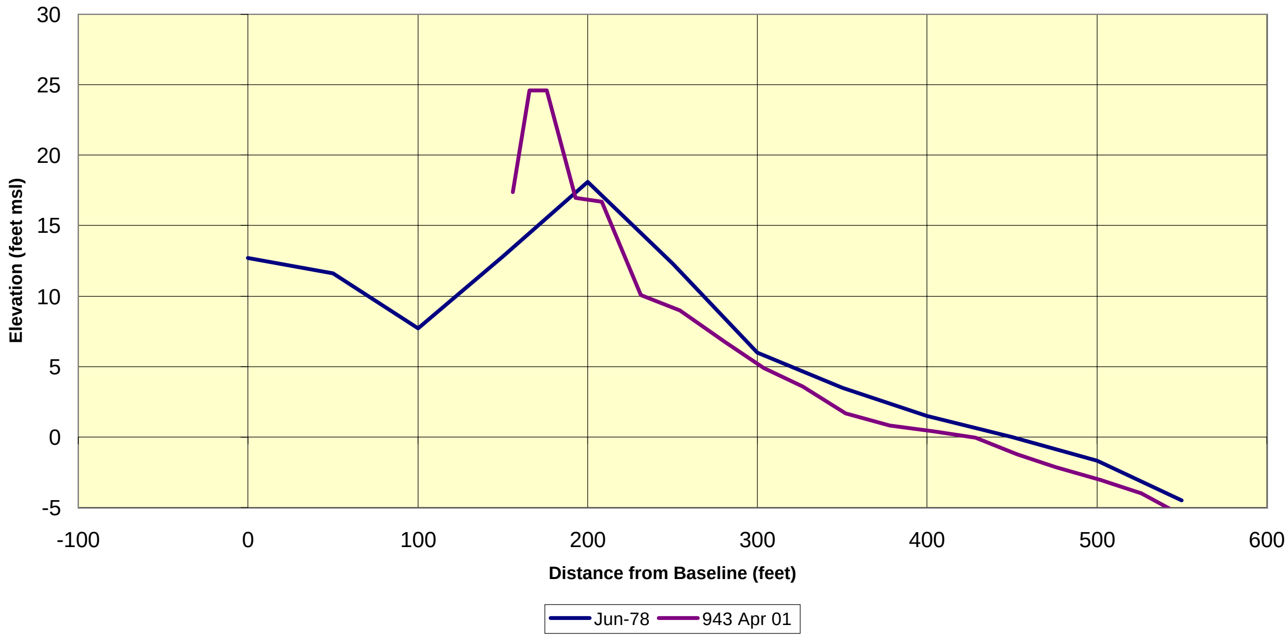


Figure A-88 Bogue Banks Station 983+77, June 1978 Station 982+81, April 2001 (West Emerald Isle)

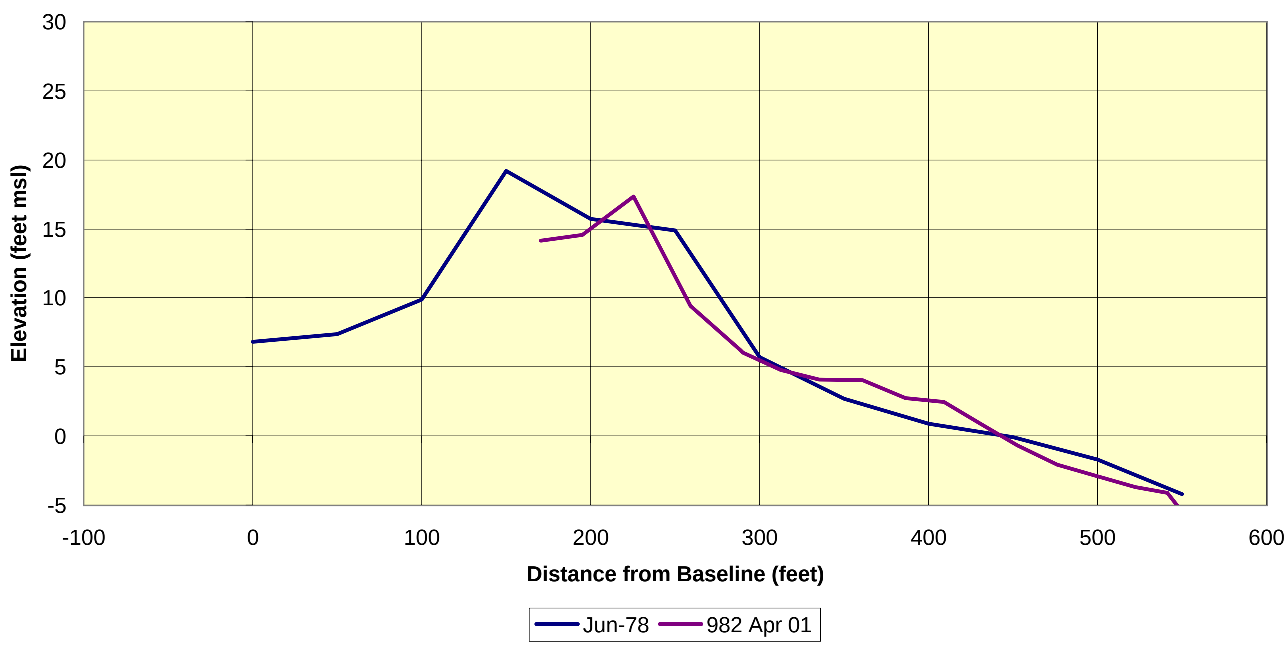


Figure A-89 Bogue Banks Station 1025+90, June 1978
Station 1022+37, April 2001
(West Emerald Isle)

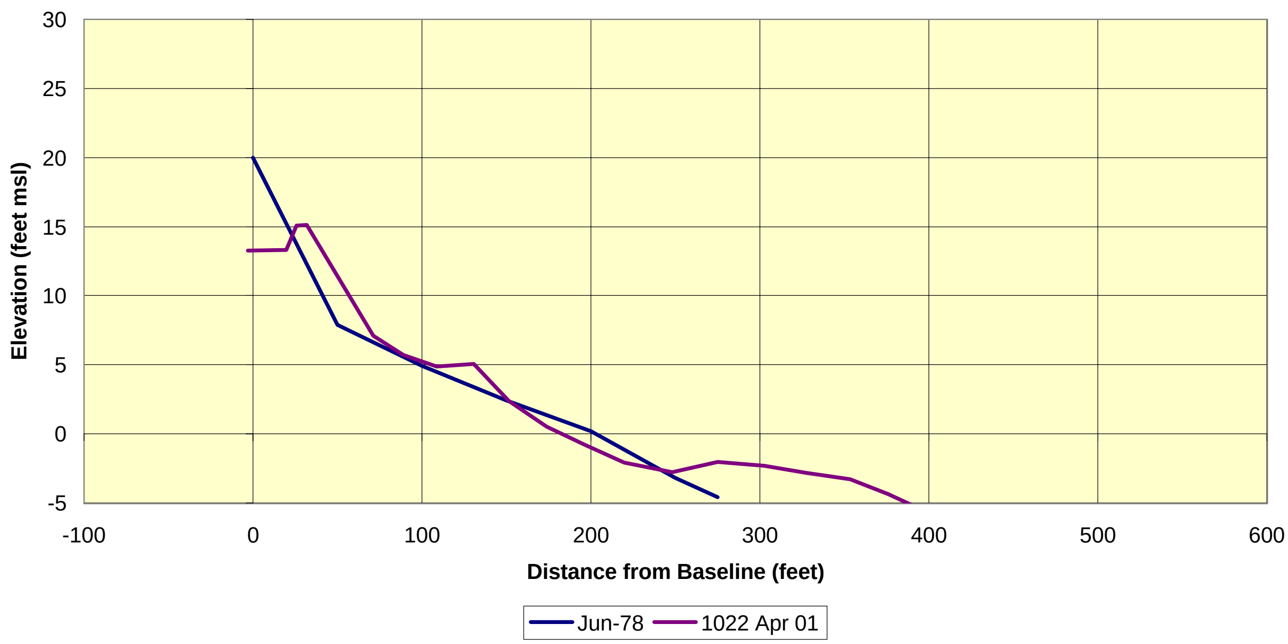


Figure A-90 Bogue Banks Station 1112+81, June 1978
Station 1113+58, April 2001
(West Emerald Isle)

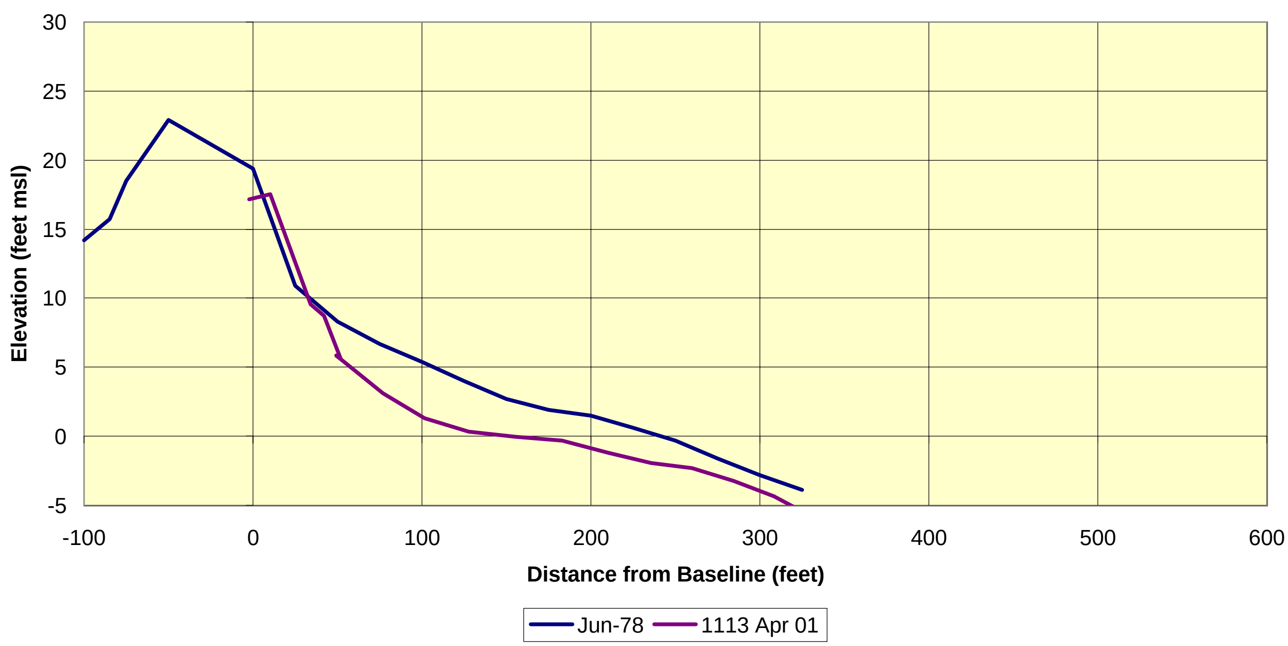


Figure A-91 Bogue Banks Station 1189+31, June 1978
Station 1192+91, April 2001
(Bogue Inlet Area)

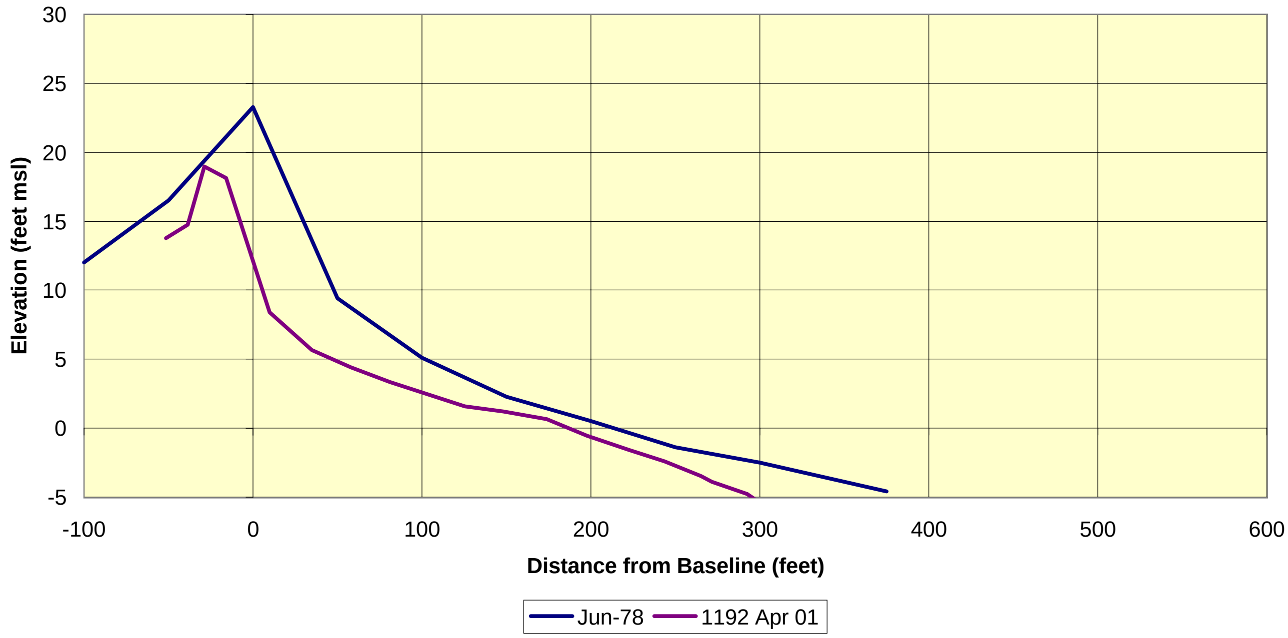


Figure A-92 Bogue Banks Station 1254+77, June 1978
Station 1252+76, April 2001
(Bogue Inlet Area)

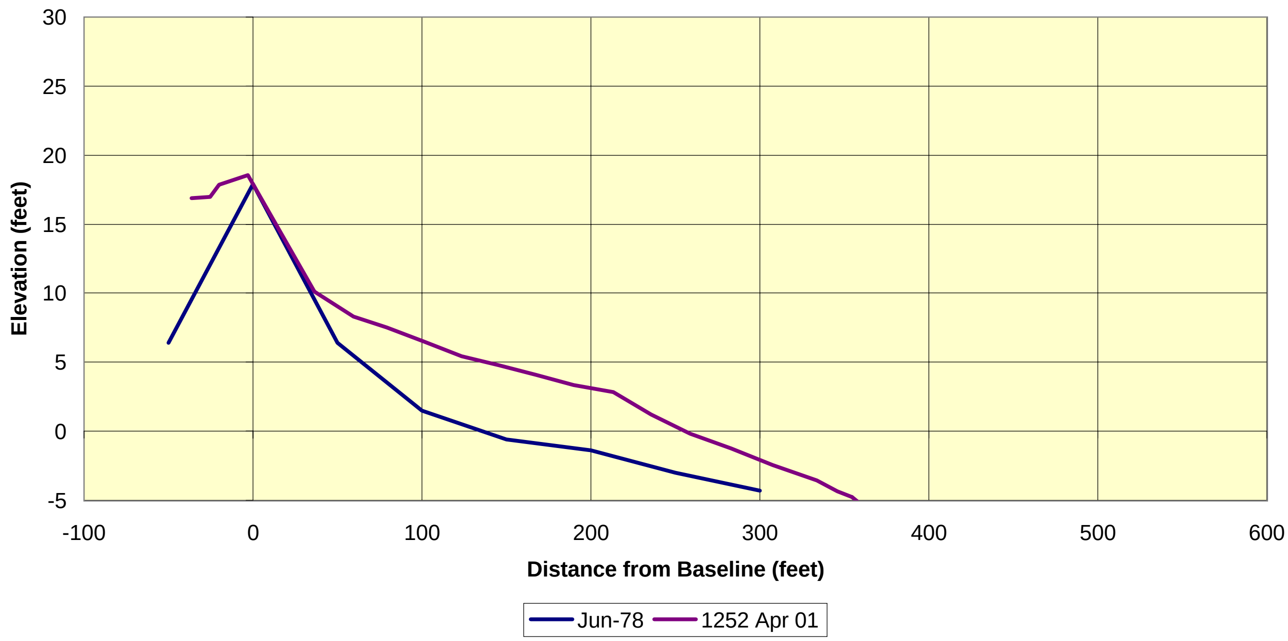


Table A-1 Bogue Banks 1933 to 1946
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
100+00	1.89	4.0
105+00	1.99	-0.1
110+00	2.08	-1.4
115+00	2.18	-0.2
120+00	2.27	-2.4
125+00	2.37	-1.4
130+00	2.46	-0.6
135+00	2.56	-0.1
140+00	2.65	0.0
145+00	2.75	-0.9
150+00	2.84	-4.3
155+00	2.94	-4.2
160+00	3.03	-6.1
165+00	3.13	-6.6
170+00	3.22	-5.5
175+00	3.31	-4.1
180+00	3.41	-1.9
185+00	3.50	-1.6
190+00	3.60	-1.4
195+00	3.69	0.4
200+00	3.79	0.1
205+00	3.88	2.3
210+00	3.98	2.5
215+00	4.07	2.9
220+00	4.17	4.5
225+00	4.26	4.0
230+00	4.36	4.9
235+00	4.45	5.2
240+00	4.55	4.0
245+00	4.64	2.0
250+00	4.73	0.3
255+00	4.83	0.1
260+00	4.92	1.2
265+00	5.02	1.7
270+00	5.11	-0.5
275+00	5.21	-1.8
280+00	5.30	1.7
285+00	5.40	0.2
290+00	5.49	0.8
295+00	5.59	0.8
300+00	5.68	1.6
305+00	5.78	-0.5
310+00	5.87	-1.8
315+00	5.97	-1.5

Atlantic Beach Average Shoreline Change Rate
-0.1

Table A-2 Bogue Banks 1946 to 1978
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
100+00	1.89	-2.7
105+00	1.99	-2.0
110+00	2.08	-2.4
115+00	2.18	-2.1
120+00	2.27	-1.3
125+00	2.37	-1.5
130+00	2.46	-2.0
135+00	2.56	-2.5
140+00	2.65	-2.8
145+00	2.75	-2.8
150+00	2.84	-1.7
155+00	2.94	-2.3
160+00	3.03	-2.0
165+00	3.13	-0.9
170+00	3.22	-1.4
175+00	3.31	-4.5
180+00	3.41	-1.4
185+00	3.50	-0.3
190+00	3.60	-0.3
195+00	3.69	-0.8
200+00	3.79	-0.8
205+00	3.88	-0.5
210+00	3.98	0.5
215+00	4.07	0.5
220+00	4.17	-0.3
225+00	4.26	-0.2
230+00	4.36	-0.6
235+00	4.45	-1.1
240+00	4.55	-0.8
245+00	4.64	-0.5
250+00	4.73	-0.4
255+00	4.83	-0.5
260+00	4.92	-0.3
265+00	5.02	-0.3
270+00	5.11	0.5
275+00	5.21	1.5
280+00	5.30	0.5
285+00	5.40	0.7
290+00	5.49	-0.1
295+00	5.59	-0.4
300+00	5.68	-0.9
305+00	5.78	-0.1
310+00	5.87	0.2
315+00	5.97	0.1

Atlantic Beach Average Shoreline Change Rate
-0.9

Table A-1 Bogue Banks 1933 to 1946 Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
320+00	6.06	-0.1
325+00	6.16	1.3
330+00	6.25	-0.6
335+00	6.34	-1.2
340+00	6.44	-4.3
345+00	6.53	-5.8
350+00	6.63	-6.3
355+00	6.72	-8.7
360+00	6.82	-6.2
365+00	6.91	-5.2
370+00	7.01	-4.8
375+00	7.10	-2.1
380+00	7.20	-1.2
385+00	7.29	-2.3
390+00	7.39	-1.8
395+00	7.48	-0.9
400+00	7.58	2.3
405+00	7.67	3.4
410+00	7.77	2.6
415+00	7.86	1.1
420+00	7.95	-0.1
425+00	8.05	0.3
430+00	8.14	1.1
435+00	8.24	1.2
440+00	8.33	1.6
445+00	8.43	4.0
450+00	8.52	2.8
455+00	8.62	2.5
460+00	8.71	1.8
465+00	8.81	2.4
470+00	8.90	3.9
475+00	9.00	5.5
480+00	9.09	2.4
485+00	9.19	1.3
490+00	9.28	0.5
495+00	9.38	1.2
500+00	9.47	1.9
505+00	9.56	1.2
510+00	9.66	1.4
515+00	9.75	1.9
520+00	9.85	0.2
525+00	9.94	1.6
530+00	10.04	3.1
535+00	10.13	2.8
540+00	10.23	4.9
545+00	10.32	4.3
550+00	10.42	3.7
555+00	10.51	4.8

Pine Knoll Shores Average Shoreline Change Rate
0.5

Table A-2 Bogue Banks 1946 to 1978 Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
320+00	6.06	-0.3
325+00	6.16	-0.4
330+00	6.25	0.6
335+00	6.34	0.0
340+00	6.44	0.4
345+00	6.53	0.8
350+00	6.63	0.8
355+00	6.72	1.5
360+00	6.82	0.9
365+00	6.91	1.7
370+00	7.01	2.6
375+00	7.10	1.4
380+00	7.20	0.7
385+00	7.29	0.8
390+00	7.39	0.5
395+00	7.48	0.8
400+00	7.58	0.1
405+00	7.67	0.1
410+00	7.77	0.3
415+00	7.86	0.8
420+00	7.95	0.9
425+00	8.05	0.5
430+00	8.14	0.5
435+00	8.24	0.5
440+00	8.33	0.4
445+00	8.43	-0.6
450+00	8.52	-0.4
455+00	8.62	-0.4
460+00	8.71	-0.3
465+00	8.81	-0.1
470+00	8.90	-0.3
475+00	9.00	-0.3
480+00	9.09	1.2
485+00	9.19	0.5
490+00	9.28	-0.9
495+00	9.38	-0.7
500+00	9.47	-0.2
505+00	9.56	-0.4
510+00	9.66	-0.9
515+00	9.75	-1.0
520+00	9.85	-0.2
525+00	9.94	-0.8
530+00	10.04	-1.3
535+00	10.13	-0.6
540+00	10.23	-0.9
545+00	10.32	-1.2
550+00	10.42	-1.6
555+00	10.51	-1.7

Pine Knoll Shores Average Shoreline Change Rate
0.1

Table A-1 Bogue Banks 1933 to 1946
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
560+00	10.61	2.6
565+00	10.70	1.5
570+00	10.80	0.1
575+00	10.89	0.8
580+00	10.98	-0.4
585+00	11.08	0.3
590+00	11.17	-2.2
595+00	11.27	-4.5
600+00	11.36	-3.7
605+00	11.46	-3.2
610+00	11.55	-3.5
615+00	11.65	-3.4
620+00	11.74	-3.2
625+00	11.84	-2.3
630+00	11.93	-4.2
635+00	12.03	-5.0
640+00	12.12	-4.9
645+00	12.22	-4.4
650+00	12.31	-3.9
655+00	12.41	-4.4
660+00	12.50	-5.6
665+00	12.59	-8.1
670+00	12.69	-7.6
675+00	12.78	-6.3
680+00	12.88	-6.1
685+00	12.97	-7.5
690+00	13.07	-7.1
695+00	13.16	-8.0
700+00	13.26	-7.9
705+00	13.35	-8.8
710+00	13.45	-5.0
715+00	13.54	-8.4
720+00	13.64	-9.3
725+00	13.73	-11.1
730+00	13.83	-12.1
735+00	13.92	-11.4
740+00	14.02	-9.8
745+00	14.11	-8.6
750+00	14.20	-7.7
755+00	14.30	-6.3
760+00	14.39	-5.2
765+00	14.49	-5.4
770+00	14.58	-5.5
775+00	14.68	-5.4
780+00	14.77	-4.9
785+00	14.87	-3.4
790+00	14.96	-3.4
795+00	15.06	-1.9
800+00	15.15	-0.5
805+00	15.25	0.6
810+00	15.34	1.4
815+00	15.44	1.9
820+00	15.53	1.5
825+00	15.63	0.8
830+00	15.72	0.6
835+00	15.81	0.9
840+00	15.91	1.3
845+00	16.00	1.0
850+00	16.10	0.1
855+00	16.19	3.3
860+00	16.29	7.3
865+00	16.38	2.1
870+00	16.48	-1.2
875+00	16.57	0.7
880+00	16.67	0.4
885+00	16.76	1.5
890+00	16.86	1.4
895+00	16.95	1.5
900+00	17.05	0.7
905+00	17.14	0.8

Indian Beach Average
Shoreline Change Rate
-3.4

East Emerald Isle Average
Shoreline Change Rate
-3.6

Table A-2 Bogue Banks 1946 to 1978
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
560+00	10.61	-0.9
565+00	10.70	-1.5
570+00	10.80	-1.6
575+00	10.89	-1.3
580+00	10.98	-0.3
585+00	11.08	-1.0
590+00	11.17	-0.5
595+00	11.27	-0.1
600+00	11.36	-0.6
605+00	11.46	-0.8
610+00	11.55	-0.7
615+00	11.65	-1.3
620+00	11.74	-1.9
625+00	11.84	-2.2
630+00	11.93	-1.6
635+00	12.03	-1.2
640+00	12.12	-0.8
645+00	12.22	-0.8
650+00	12.31	-0.7
655+00	12.41	-0.5
660+00	12.50	-0.9
665+00	12.59	0.0
670+00	12.69	-0.3
675+00	12.78	-0.9
680+00	12.88	-1.1
685+00	12.97	-0.4
690+00	13.07	-0.4
695+00	13.16	0.0
700+00	13.26	-0.1
705+00	13.35	-0.2
710+00	13.45	-0.4
715+00	13.54	-0.2
720+00	13.64	0.5
725+00	13.73	0.8
730+00	13.83	0.9
735+00	13.92	0.5
740+00	14.02	0.2
745+00	14.11	0.4
750+00	14.20	0.4
755+00	14.30	0.0
760+00	14.39	-0.2
765+00	14.49	0.0
770+00	14.58	0.1
775+00	14.68	0.1
780+00	14.77	0.0
785+00	14.87	-0.6
790+00	14.96	-0.1
795+00	15.06	0.2
800+00	15.15	0.6
805+00	15.25	1.0
810+00	15.34	1.0
815+00	15.44	0.8
820+00	15.53	1.0
825+00	15.63	1.6
830+00	15.72	1.9
835+00	15.81	1.8
840+00	15.91	1.6
845+00	16.00	1.7
850+00	16.10	2.1
855+00	16.19	2.6
860+00	16.29	1.9
865+00	16.38	3.1
870+00	16.48	4.0
875+00	16.57	3.4
880+00	16.67	3.4
885+00	16.76	2.5
890+00	16.86	2.5
895+00	16.95	2.5
900+00	17.05	2.5
905+00	17.14	1.5

Indian Beach Average
Shoreline Change Rate
-0.9

East Emerald Isle Average
Shoreline Change Rate
1.1

Table A-3 Bogue Banks 1978 to 1993
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
100+00	1.89	0.9
105+00	1.99	4.8
110+00	2.08	8.7
115+00	2.18	8.3
120+00	2.27	8.0
125+00	2.37	8.3
130+00	2.46	8.7
135+00	2.56	9.9
140+00	2.65	11.1
145+00	2.75	11.2
150+00	2.84	11.3
155+00	2.94	12.4
160+00	3.03	13.6
165+00	3.13	12.6
170+00	3.22	11.7
175+00	3.31	12.4
180+00	3.41	13.1
185+00	3.50	10.9
190+00	3.60	8.7
195+00	3.69	8.3
200+00	3.79	7.9
205+00	3.88	6.4
210+00	3.98	4.9
215+00	4.07	5.6
220+00	4.17	6.3
225+00	4.26	6.6
230+00	4.36	6.9
235+00	4.45	5.5
240+00	4.55	4.2
245+00	4.64	5.0
250+00	4.73	5.7
255+00	4.83	5.1
260+00	4.92	4.4
265+00	5.02	3.1
270+00	5.11	1.8
275+00	5.21	0.1
280+00	5.30	-1.6
285+00	5.40	-0.5
290+00	5.49	0.5
295+00	5.59	0.3
300+00	5.68	0.1
305+00	5.78	-0.3
310+00	5.87	-0.7
315+00	5.97	-1.7

Atlantic Beach Average Shoreline Change Rate
6.1

Table A-4 Bogue Banks 1993 to 1999
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
100+00	1.89	4.0
105+00	1.99	-1.5
110+00	2.08	-6.3
115+00	2.18	-2.9
120+00	2.27	-2.6
125+00	2.37	-3.3
130+00	2.46	-1.4
135+00	2.56	-4.5
140+00	2.65	-6.9
145+00	2.75	-7.5
150+00	2.84	-8.1
155+00	2.94	-6.9
160+00	3.03	-10.2
165+00	3.13	-9.2
170+00	3.22	-1.6
175+00	3.31	11.7
180+00	3.41	-7.2
185+00	3.50	-5.7
190+00	3.60	3.0
195+00	3.69	2.3
200+00	3.79	3.9
205+00	3.88	4.4
210+00	3.98	5.0
215+00	4.07	4.8
220+00	4.17	5.1
225+00	4.26	4.7
230+00	4.36	7.1
235+00	4.45	12.1
240+00	4.55	8.2
245+00	4.64	10.7
250+00	4.73	13.0
255+00	4.83	14.8
260+00	4.92	15.2
265+00	5.02	17.1
270+00	5.11	19.0
275+00	5.21	18.2
280+00	5.30	17.9
285+00	5.40	13.9
290+00	5.49	10.4
295+00	5.59	12.9
300+00	5.68	15.2
305+00	5.78	10.6
310+00	5.87	8.0
315+00	5.97	3.9

Atlantic Beach Average Shoreline Change Rate
4.4

Table A-3 Bogue Banks 1978 to 1993 Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
320+00	6.06	-2.7
325+00	6.16	-2.5
330+00	6.25	-2.4
335+00	6.34	-1.3
340+00	6.44	-0.1
345+00	6.53	-2.1
350+00	6.63	-4.0
355+00	6.72	-2.7
360+00	6.82	-1.5
365+00	6.91	-3.3
370+00	7.01	-5.1
375+00	7.10	-4.5
380+00	7.20	-3.8
385+00	7.29	-3.4
390+00	7.39	-3.1
395+00	7.48	-2.7
400+00	7.58	-2.3
405+00	7.67	-1.9
410+00	7.77	-1.5
415+00	7.86	-3.0
420+00	7.95	-4.5
425+00	8.05	-4.5
430+00	8.14	-4.5
435+00	8.24	-4.7
440+00	8.33	-4.8
445+00	8.43	-4.2
450+00	8.52	-3.5
455+00	8.62	-3.3
460+00	8.71	-3.1
465+00	8.81	-3.8
470+00	8.90	-4.5
475+00	9.00	-4.4
480+00	9.09	-4.3
485+00	9.19	-2.6
490+00	9.28	-0.8
495+00	9.38	-2.5
500+00	9.47	-4.2
505+00	9.56	-3.7
510+00	9.66	-3.2
515+00	9.75	-4.8
520+00	9.85	-6.4
525+00	9.94	-5.3
530+00	10.04	-4.1
535+00	10.13	-4.5
540+00	10.23	-4.9
545+00	10.32	-3.6
550+00	10.42	-2.3
555+00	10.51	-3.4

Pine Knoll Shores Average Shoreline Change Rate
-3.4

Table A-4 Bogue Banks 1993 to 1999 Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr
320+00	6.06	8.7
325+00	6.16	5.5
330+00	6.25	2.8
335+00	6.34	2.0
340+00	6.44	1.5
345+00	6.53	5.2
350+00	6.63	8.2
355+00	6.72	2.2
360+00	6.82	-3.6
365+00	6.91	-4.3
370+00	7.01	-3.5
375+00	7.10	-4.4
380+00	7.20	-1.1
385+00	7.29	0.2
390+00	7.39	0.7
395+00	7.48	-0.2
400+00	7.58	-1.1
405+00	7.67	-1.9
410+00	7.77	-2.9
415+00	7.86	0.4
420+00	7.95	1.8
425+00	8.05	-0.8
430+00	8.14	-3.6
435+00	8.24	-2.5
440+00	8.33	-0.2
445+00	8.43	-1.7
450+00	8.52	-1.7
455+00	8.62	-1.2
460+00	8.71	-1.4
465+00	8.81	-1.1
470+00	8.90	-0.4
475+00	9.00	-2.2
480+00	9.09	-5.1
485+00	9.19	-5.7
490+00	9.28	-1.9
495+00	9.38	-0.3
500+00	9.47	0.9
505+00	9.56	2.4
510+00	9.66	0.2
515+00	9.75	-3.2
520+00	9.85	-7.3
525+00	9.94	-30.1
530+00	10.04	-15.6
535+00	10.13	-6.9
540+00	10.23	-2.5
545+00	10.32	-3.0
550+00	10.42	-3.6
555+00	10.51	-4.8

Pine Knoll Shores Average Shoreline Change Rate
-1.8

Table A-3 Bogue Banks 1978 to 1993
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr	
560+00	10.61	-4.5	
565+00	10.70	-3.9	
570+00	10.80	-3.3	
575+00	10.89	-4.6	
580+00	10.98	-5.9	
585+00	11.08	-5.6	
590+00	11.17	-5.3	
595+00	11.27	-5.3	
600+00	11.36	-5.4	
605+00	11.46	-5.1	
610+00	11.55	-4.7	
615+00	11.65	-3.5	
620+00	11.74	-2.3	
625+00	11.84	-2.3	
630+00	11.93	-2.3	
635+00	12.03	-2.6	
640+00	12.12	-2.9	
645+00	12.22	-3.0	**East Emerald Isle Average**
650+00	12.31	-3.1	**Shoreline Change Rate**
655+00	12.41	-3.3	**-3.9**
660+00	12.50	-3.5	
665+00	12.59	-3.6	
670+00	12.69	-3.6	
675+00	12.78	-3.7	
680+00	12.88	-3.7	
685+00	12.97	-3.9	
690+00	13.07	-4.0	
695+00	13.16	-3.7	
700+00	13.26	-3.5	
705+00	13.35	-2.9	
710+00	13.45	-2.3	
715+00	13.54	-2.8	
720+00	13.64	-3.4	
725+00	13.73	-3.2	
730+00	13.83	-3.0	
735+00	13.92	-3.7	
740+00	14.02	-4.3	
745+00	14.11	-4.3	
750+00	14.20	-4.2	
755+00	14.30	-3.8	
760+00	14.39	-3.5	
765+00	14.49	-3.4	
770+00	14.58	-3.3	
775+00	14.68	-4.1	
780+00	14.77	-4.9	
785+00	14.87	-4.5	
790+00	14.96	-4.1	
795+00	15.06	-4.3	
800+00	15.15	-4.4	
805+00	15.25	-4.5	
810+00	15.34	-4.5	
815+00	15.44	-4.7	
820+00	15.53	-4.8	
825+00	15.63	-5.1	
830+00	15.72	-5.5	**East Emerald Isle Average**
835+00	15.81	-5.6	**Shoreline Change Rate**
840+00	15.91	-5.7	**-3.9**
845+00	16.00	-4.5	
850+00	16.10	-3.3	
855+00	16.19	-2.5	
860+00	16.29	-1.7	
865+00	16.38	-3.5	
870+00	16.48	-5.2	
875+00	16.57	-2.7	
880+00	16.67	-0.3	
885+00	16.76	-2.8	
890+00	16.86	-5.3	
895+00	16.95	-5.6	
900+00	17.05	-5.9	
905+00	17.14	-4.4	

Table A-4 Bogue Banks 1993 to 1999
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr	
560+00	10.61	-5.9	
565+00	10.70	-5.7	
570+00	10.80	-3.9	
575+00	10.89	-2.6	
580+00	10.98	-2.1	
585+00	11.08	-3.2	
590+00	11.17	-3.9	
595+00	11.27	-2.8	
600+00	11.36	-1.8	
605+00	11.46	-2.4	
610+00	11.55	-4.4	
615+00	11.65	-4.4	
620+00	11.74	-5.1	
625+00	11.84	-4.5	
630+00	11.93	-3.7	
635+00	12.03	-2.2	
640+00	12.12	-2.8	
645+00	12.22	-5.2	**Indian Beach Average**
650+00	12.31	-7.1	**Shoreline Change Rate**
655+00	12.41	-5.6	**-3.7**
660+00	12.50	-3.5	
665+00	12.59	-3.5	
670+00	12.69	-3.4	
675+00	12.78	-2.3	
680+00	12.88	-1.6	
685+00	12.97	-1.8	
690+00	13.07	-1.7	
695+00	13.16	-3.7	
700+00	13.26	-5.8	
705+00	13.35	2.6	
710+00	13.45	1.8	
715+00	13.54	-1.2	
720+00	13.64	-4.1	
725+00	13.73	-3.8	
730+00	13.83	-2.7	
735+00	13.92	0.2	
740+00	14.02	2.5	
745+00	14.11	1.7	
750+00	14.20	1.2	
755+00	14.30	-0.3	
760+00	14.39	-2.9	
765+00	14.49	-4.4	
770+00	14.58	-5.1	
775+00	14.68	-2.5	
780+00	14.77	1.4	
785+00	14.87	1.9	
790+00	14.96	-0.9	
795+00	15.06	-3.1	
800+00	15.15	-2.5	
805+00	15.25	-2.0	
810+00	15.34	-2.5	
815+00	15.44	-1.7	
820+00	15.53	6.1	
825+00	15.63	3.5	**East Emerald Isle Average**
830+00	15.72	-0.6	**Shoreline Change Rate**
835+00	15.81	-0.6	**-1.6**
840+00	15.91	-0.3	
845+00	16.00	-3.0	
850+00	16.10	-19.8	
855+00	16.19	-16.4	
860+00	16.29	-9.5	
865+00	16.38	-0.8	
870+00	16.48	-0.6	
875+00	16.57	-0.9	
880+00	16.67	-0.8	
885+00	16.76	2.0	
890+00	16.86	4.9	
895+00	16.95	3.4	
900+00	17.05	2.3	
905+00	17.14	0.3	

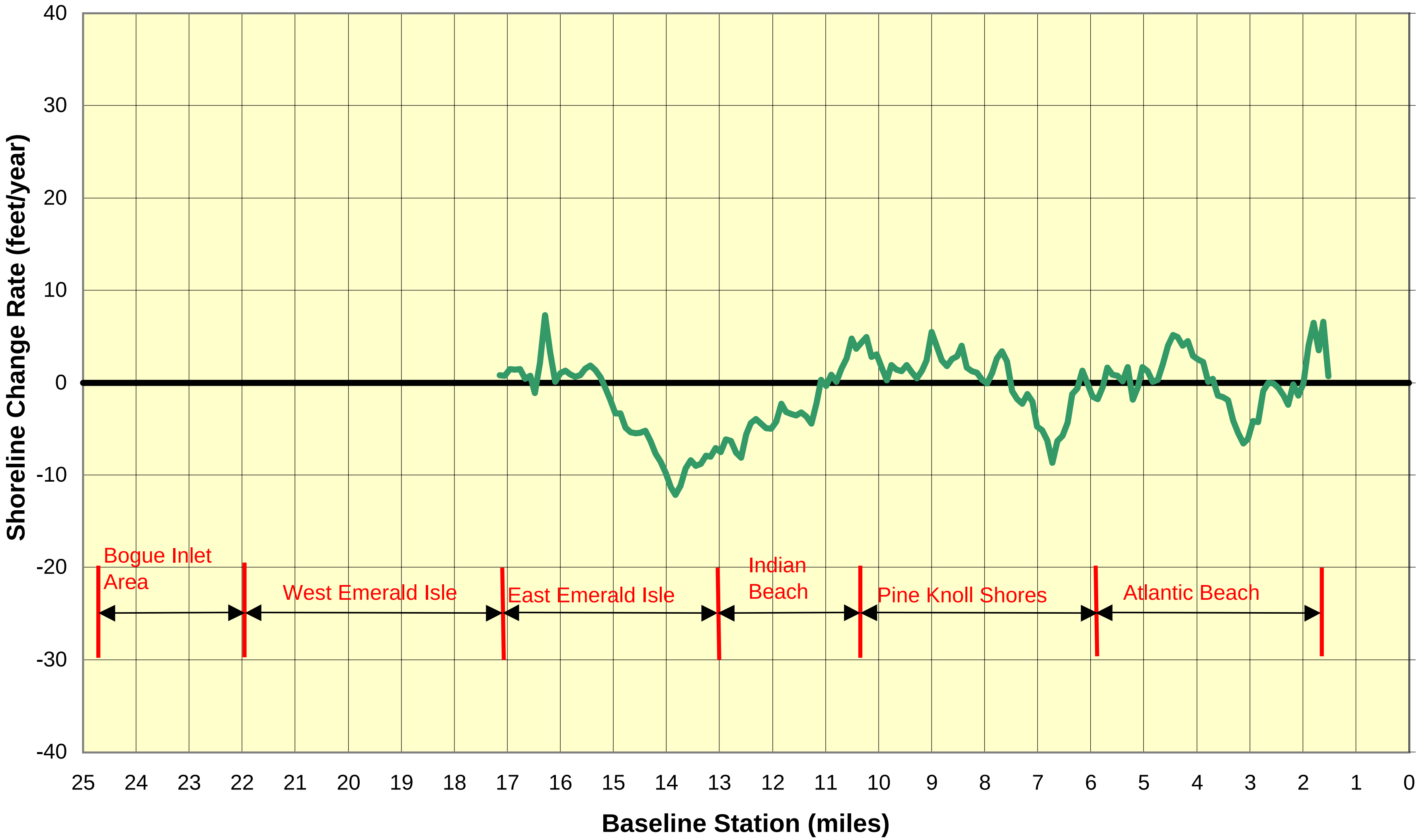
Table A-3 Bogue Banks 1978 to 1993
Shoreline Change Rates

Baseline Station feet	Baseline Station miles	SL Change ft/yr	
910+00	17.23	-2.9	
915+00	17.33	-3.3	
920+00	17.42	-3.7	
925+00	17.52	-3.7	
930+00	17.61	-3.7	
935+00	17.71	-4.1	
940+00	17.80	-4.4	
945+00	17.90	-4.5	
950+00	17.99	-4.7	
955+00	18.09	-4.5	
960+00	18.18	-4.4	
965+00	18.28	-3.6	
970+00	18.37	-2.8	
975+00	18.47	-3.1	
980+00	18.56	-3.5	
985+00	18.66	-3.5	
990+00	18.75	-3.6	
995+00	18.84	-2.6	
1000+00	18.94	-1.6	
1005+00	19.03	-2.5	
1010+00	19.13	-3.3	
1015+00	19.22	-2.1	
1020+00	19.32	-0.8	
1025+00	19.41	-0.4	
1030+00	19.51	0.1	
1035+00	19.60	-2.7	
1040+00	19.70	-5.5	
1045+00	19.79	-3.5	
1050+00	19.89	-1.6	
1055+00	19.98	-1.3	
1060+00	20.08	-1.1	
1065+00	20.17	-2.5	
1070+00	20.27	-4.0	**West Emerald Average**
1075+00	20.36	-3.4	**Shoreline Change Rate**
1080+00	20.45	-2.9	**-2.7**
1085+00	20.55	-3.2	
1090+00	20.64	-3.5	
1095+00	20.74	-2.4	
1100+00	20.83	-1.3	
1105+00	20.93	-3.0	
1110+00	21.02	-4.7	
1115+00	21.12	-3.2	
1120+00	21.21	-1.7	
1125+00	21.31	-2.2	
1130+00	21.40	-2.7	
1135+00	21.50	-2.7	
1140+00	21.59	-2.7	
1145+00	21.69	-0.5	
1150+00	21.78	1.6	
1155+00	21.88	0.9	
1160+00	21.97	0.3	
1165+00	22.06	-1.2	
1170+00	22.16	-2.7	
1175+00	22.25	-2.7	
1180+00	22.35	-2.6	
1185+00	22.44	-2.3	
1190+00	22.54	-2.1	
1195+00	22.63	-2.4	
1200+00	22.73	-2.7	
1205+00	22.82	-2.5	
1210+00	22.92	-2.2	
1215+00	23.01	-3.0	
1220+00	23.11	-3.7	
1225+00	23.20	-2.8	
1230+00	23.30	-1.9	
1235+00	23.39	-0.8	
1240+00	23.48	0.2	
1245+00	23.58	1.4	
1250+00	23.67	2.7	
1255+00	23.77	0.8	
1260+00	23.86	-1.1	
1265+00	23.96	1.4	**Bogue Inlet Area Average**
1270+00	24.05	3.8	**Shoreline Change Rate**
1275+00	24.15	6.0	**3.2**
1280+00	24.24	8.3	
1285+00	24.34	12.7	
1290+00	24.43	17.2	
1295+00	24.53	18.2	
1300+00	24.62	19.1	
1305+00	24.72	20.7	
1310+00	24.81	22.3	

Table A-4 Bogue Banks 1993 to 1999
Shoreline Change Rates

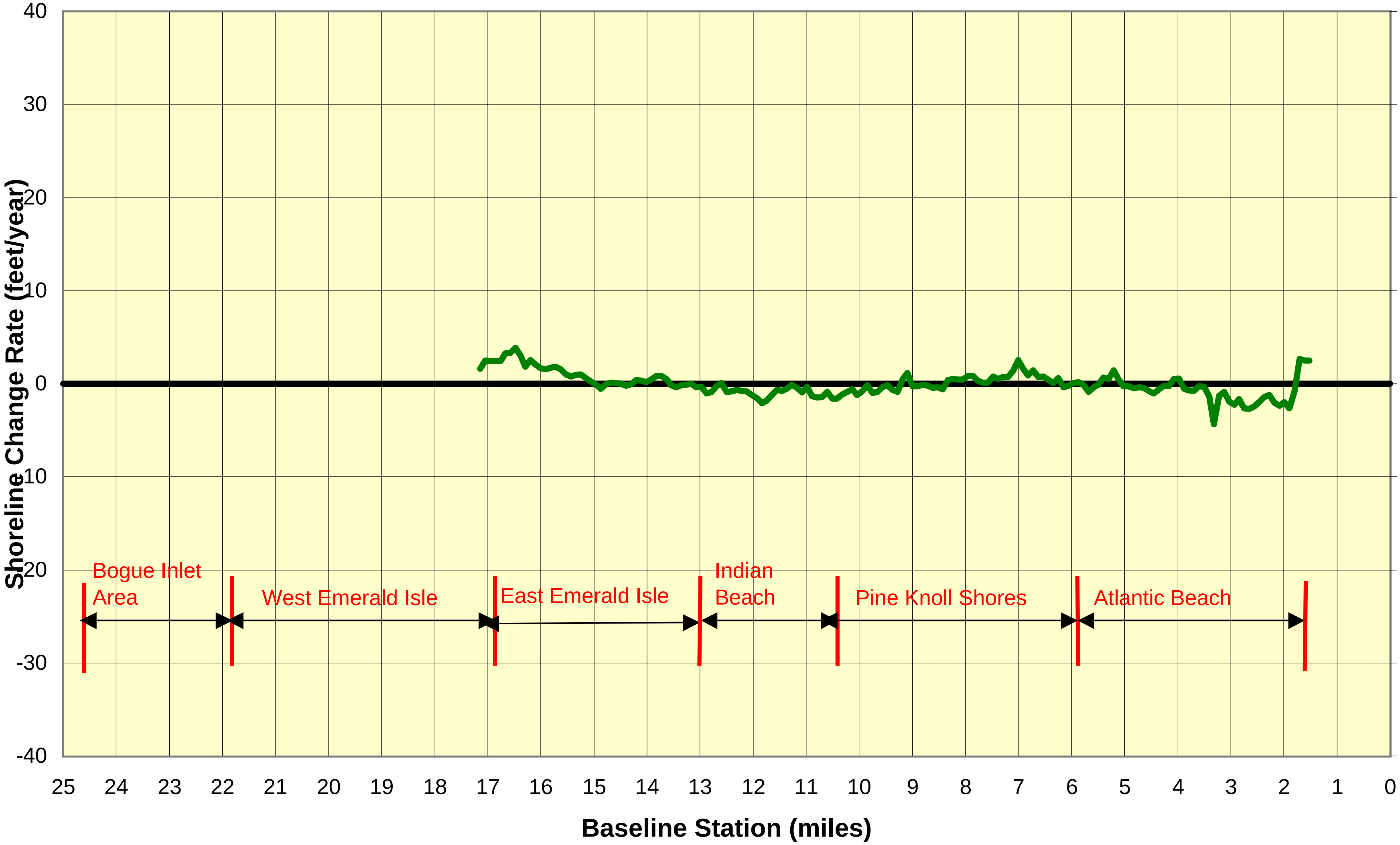
Baseline Station feet	Baseline Station miles	SL Change ft/yr	
910+00	17.23	-1.8	
915+00	17.33	-3.1	
920+00	17.42	-1.3	
925+00	17.52	-0.9	
930+00	17.61	-0.6	
935+00	17.71	2.2	
940+00	17.80	6.9	
945+00	17.90	11.4	
950+00	17.99	13.4	
955+00	18.09	14.3	
960+00	18.18	7.5	
965+00	18.28	0.0	
970+00	18.37	-1.0	
975+00	18.47	1.6	
980+00	18.56	5.0	
985+00	18.66	4.7	
990+00	18.75	2.1	
995+00	18.84	-0.5	
1000+00	18.94	-2.4	
1005+00	19.03	1.7	
1010+00	19.13	0.8	
1015+00	19.22	6.4	
1020+00	19.32	10.7	
1025+00	19.41	12.1	
1030+00	19.51	1.6	
1035+00	19.60	-1.9	
1040+00	19.70	1.3	
1045+00	19.79	-0.5	
1050+00	19.89	-2.4	
1055+00	19.98	-3.0	
1060+00	20.08	-4.1	
1065+00	20.17	-3.2	**West Emerald Isle Average**
1070+00	20.27	-0.3	**Shoreline Change Rate**
1075+00	20.36	-0.9	**0.3**
1080+00	20.45	-3.1	
1085+00	20.55	-3.2	
1090+00	20.64	-2.9	
1095+00	20.74	-5.1	
1100+00	20.83	-6.6	
1105+00	20.93	-5.6	
1110+00	21.02	-4.3	
1115+00	21.12	-3.5	
1120+00	21.21	-2.5	
1125+00	21.31	-1.6	
1130+00	21.40	-0.4	
1135+00	21.50	-0.9	
1140+00	21.59	-0.6	
1145+00	21.69	-4.6	
1150+00	21.78	-8.5	
1155+00	21.88	-7.3	
1160+00	21.97	-1.9	
1165+00	22.06	5.5	
1170+00	22.16	5.9	
1175+00	22.25	5.4	
1180+00	22.35	5.9	
1185+00	22.44	5.4	
1190+00	22.54	4.4	
1195+00	22.63	5.3	
1200+00	22.73	6.3	
1205+00	22.82	5.1	
1210+00	22.92	7.5	
1215+00	23.01	12.5	
1220+00	23.11	13.2	
1225+00	23.20	-19.6	
1230+00	23.30	-35.0	
1235+00	23.39	-27.5	
1240+00	23.48	-2.5	
1245+00	23.58	10.8	
1250+00	23.67	15.1	
1255+00	23.77	16.9	
1260+00	23.86	23.5	**Bogue Inlet Area Average**
1265+00	23.96	26.4	**Shoreline Change Rate**
1270+00	24.05	29.1	**10.5**
1275+00	24.15	31.7	
1280+00	24.24	34.6	
1285+00	24.34	26.3	
1290+00	24.43	17.8	
1295+00	24.53	9.7	
1300+00	24.62	21.8	
1305+00	24.72	39.1	
1310+00	24.81	13.6	

Figure A-93 Bogue Banks Shoreline Change Rates 1933 to 1946 (Data Source Table A-1)



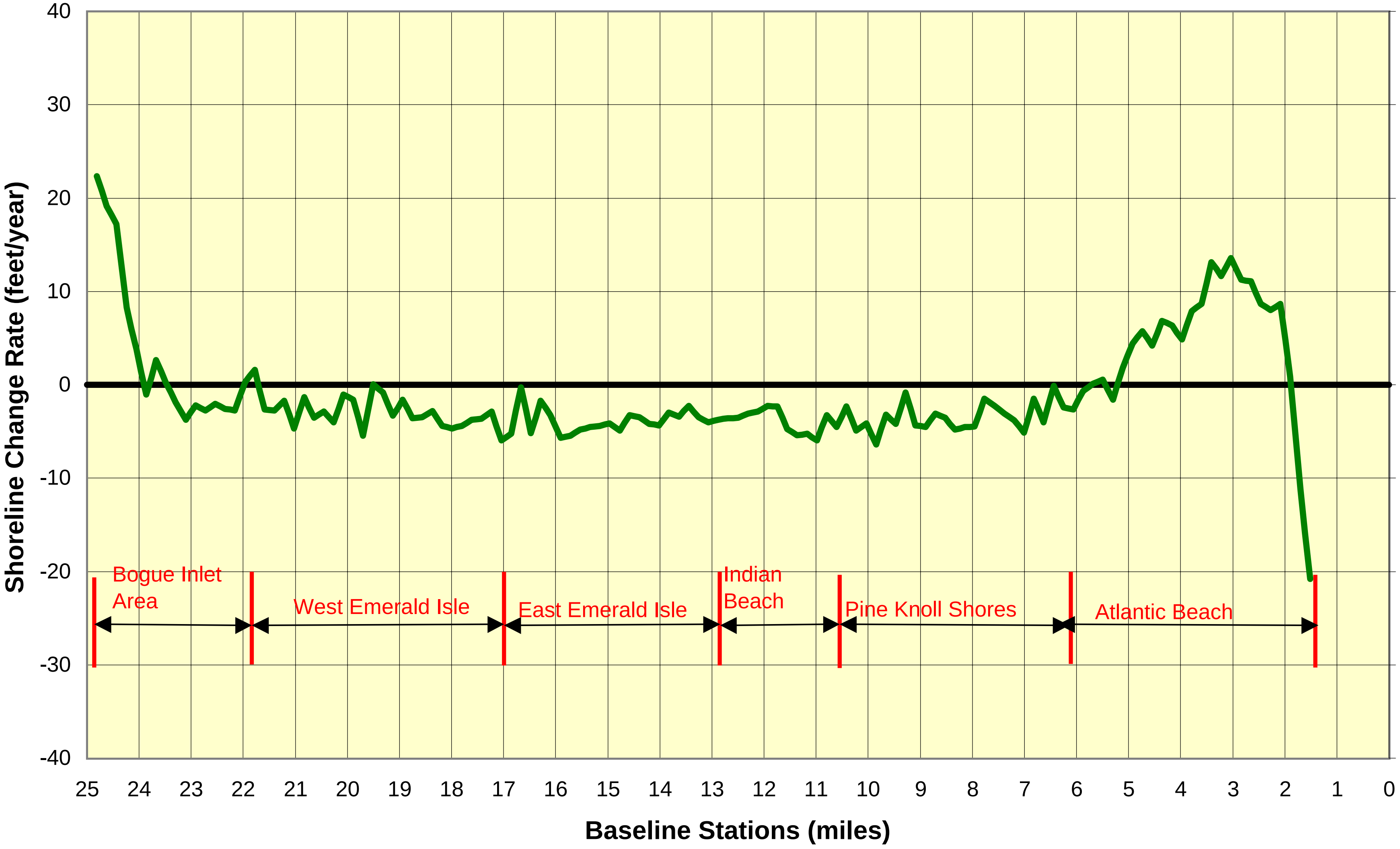
BB_Sediment_Budget_Master_List
plot 33 to 46 rates

Figure A-94 Bogue Banks Shoreline Chage Rates 1946 to 1978
(Data Source Table A-2)



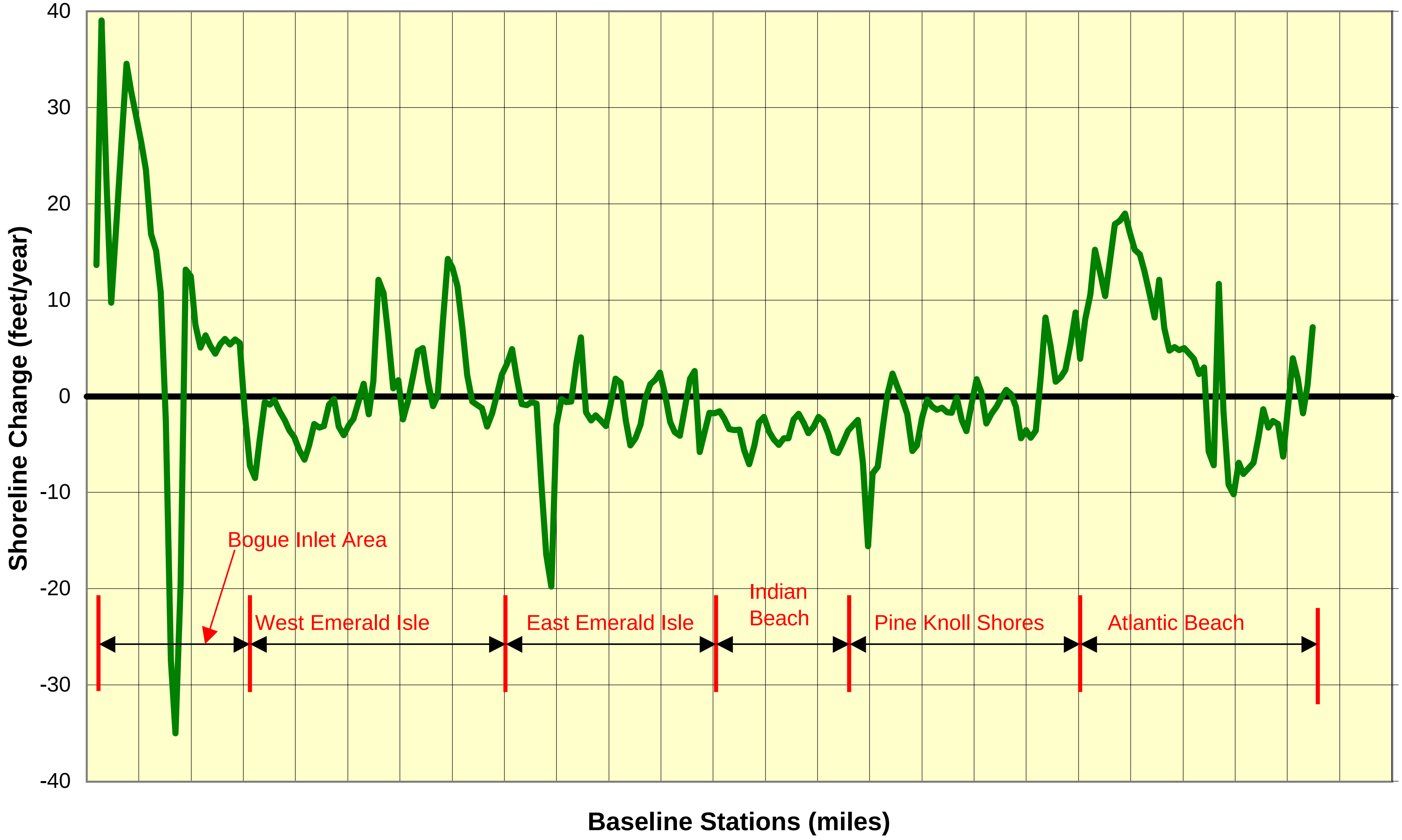
BB_Sediment_Budget_Master_List
plot 46 to 78 Rates

Figure A-95 Bogue Banks Shoreline Change Rates 1978 to 1993
(Data Source Table A-3)



BB_Sediment_Budget_Master_List
plot 78 to 93 rates

Figure A-96 Bogue Banks Shoreline Change Rates 1993 to 1999 (Data Source Table A-4)



BB_Sediment_Budget_Master_List
plot 93 to 99 rates

APPENDIX B

MORHEAD CITY HARBOR DREDGING HISTORY

	Table B-1 Dredging History for the Morehead City Harbor Project		
	Entrance Channel	Entrance Channel	Inner Harbor
Fiscal Year	Notes:	Hopper Dredge	Notes:
		(cubic yards)	
1911	New Work	237,000	
1912		-	
1913		-	
1914		-	
1915		169,300	
1916		203,700	
1917		64,700	
1918		-	
1919		-	
1920		-	
1921		-	
1922		-	
1923		-	
1924		-	
1925		-	
1926		-	
1927		311,300	
1928		156,900	
1929		209,400	
1930		166,300	
1931		-	
1932		56,100	
1933		156,300	
1934		-	
1935		763,100	
1936	New work	3,460,100	New work
Total 1912 to 1935		**2,494,100**	
Average 1911 to 1935		**99,764**	
Total New and Maint. 1911 to 1936		**5,954,200**	
1937		268,300	
1938		205,700	
1939		473,800	
1940		918,100	
1941		-	
1942		299,200	
1943		91,900	
1944		584,900	
1945		520,800	
1946		145,800	
1947		48,800	
1948		542,900	
1949		1,103,000	
1950		637,900	
1951		616,800	
1952		504,600	
Total Maint. 1937 to 1952		**6,962,500**	
Average Maint. 37 to 52		**435,156**	

	Table B-1 Dredging History for the Morehead City Harbor Project		
	Entrance Channel	Entrance Channel	Inner Harbor
Fiscal Year	Notes:	Hopper Dredge	Notes:
		(cubic yards)	
1953		312,200	
1954		797,100	
1955		719,200	
1956		564,200	
1957		1,039,500	
1958		866,800	
1959		977,400	
1960		589,400	
Total Maint. 1953 to 1960		**5,865,800**	
Average 53 to 60		**733,225**	
Total Maint. 1937 to 1960 (30-foot project)		**12,828,300**	
Average Maint. 37 to 60 (30-foot project)		**534,513**	
1961	New work	1,869,200	New work
1962		898,600	
1963		584,800	
1964		407,800	
1965		655,000	
1966		691,800	
1967		966,000	
1968		708,600	
1969		401,800	
1970		853,900	
1971		913,800	
1972		783,700	
1973		952,900	
1974		401,600	
Total Maint. 1962 to 1974		**9,220,300**	
Average Maint. 62 to 74		**709,254**	
Total New & Maint. 61 to 74		**11,089,500**	
1975		428,686	
1976		658,614	
1977		96,133	
Total Maint. 1962 to 1977 (35-foot project)		**10,403,733**	
Average Maint. 62 to 77 (35-foot project)		**650,233**	
1978	New work	2,972,200	**New work (to Bogue Bks)**
1978		530,008	
1979		0	
1980		294,610	
1981		824,052	
1982		977,040	
1983		848,933	
1984		1,098,259	
1985		583,181	
1986		367,681	Brandt Island Pumpout
			Inner Harbor
			Total to Bogue Banks
1987		534,555	
1988		691,190	
Total Maint. 1975 to 1988		**7,932,942**	
Average Maint. 75 to 88		**610,226**	
Total New and Maint. 75 to 88		**10,905,142**	

	Table B-1 Dredging History for the Morehead City Harbor Project		
	Entrance Channel	Entrance Channel	Inner Harbor
Fiscal Year	Notes:	Hopper Dredge	Notes:
		(cubic yards)	
1989		539,192	
1990		592,232	
1991		11,959	
1992		831,637	
1993		837,573	
1994	New work	2,112,584	New work
	Maintenance	494,338	Maintenance
			Brandt Island
			Total to Bogue Banks
Total Maint. 1978 to 1994 (40-foot project)	9,231,822	**10,056,440**	
Average Maint. 78 to 94 (40-foot project)	615454.8	**591,555**	
1995		0	
1996		656,646	
1997		191,872	
1998		1,163,563	
1999		1,040,919	
2000		1,701,659	
Total Maint. 1996 to 2000 (45-foot project)		**4,754,659**	
Average Maint. 96 to 00 (45-foot project)		**950,932**	
Total Maint. 1978 to 1999		**13,109,440**	
Average Maint. 78 to 99		**624,259**	
Total Maint. 1978 to 2000		**14,811,099**	
Average Maint. 78 to 00		**643,961**	
1936 to 2000			
Total Maintenance		**38,043,132**	
Total New Work		**10,414,084**	
Total New Work & Maintenance		**48,457,216**	

APPENDIX C

STORM HISTORY

APPENDIX C
STORM INTENSITY FACTORS

C-1. General. This Appendix contains Table C-1, which list all of the tropical storms that affected the study area between 1986 and 1999 and the associated Storm Intensity Factor for each storm. The table also contains the average annual Storm Intensity Factor for various time periods pertinent to the shoreline change analysis and changes in the ebb tide delta of Beaufort Inlet. A plot of the Storm Intensity Factor for each storm versus time is provided on Figure C-1.

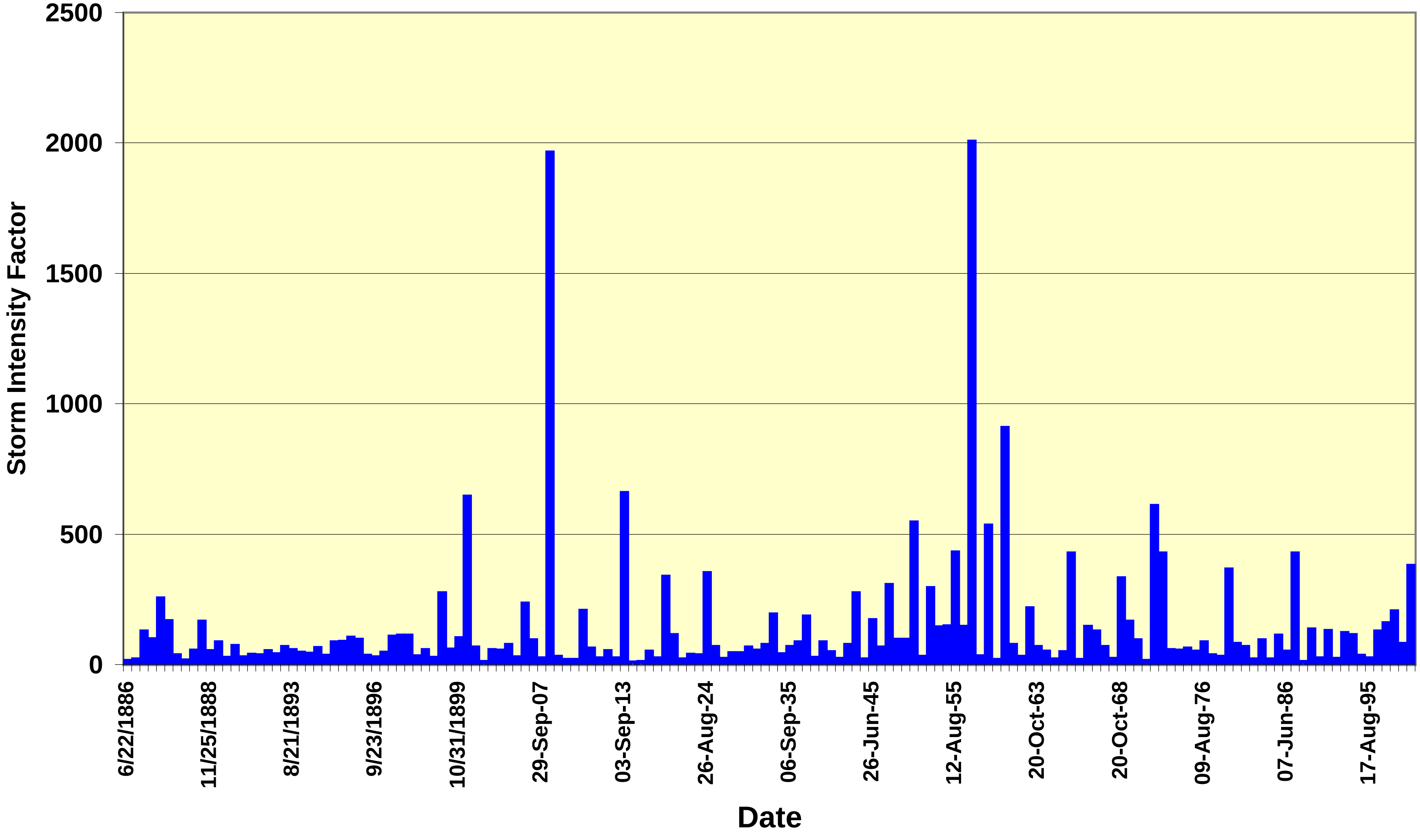
C-2. Figure C-2 is a plot of the average annual rate of shoreline change, determined over various time periods, versus the average annual Storm Intensity Factor for that time period for Atlantic Beach, Pine Knoll Shores, Indian Beach, and East Emerald Isle. The plot reveals no definitive relationship between the annual rate of shoreline change for the four shoreline segments and storm intensity, particularly for Atlantic Beach and Pine Knoll Shores. There do appear to be weak trends for Indian Beach and East Emerald Isle except the apparent trends indicate that these beaches suffer less erosion during active storm periods. This is completely opposite the expected trend. Apparently, the time periods used for the shoreline and volume change analyses are too large to capture the impacts of singular and multiple storm events. For example, even though 1946 to 1978 was an extremely active storm period, the 32-year time period combined with the absence of significant storms during the last 5 years of this period (1972 to 1978) probably allowed time for the beaches to recover, thus indicating very little storm impact. For the relatively short active storm period of 1993 to 1999, three of the beach segments, Pine Knoll Shores, Indian Beach, and East Emerald Isle, experienced considerable shoreline erosion. The last storm to impact the area during this period was Hurricane Bonnie in August 1998. Therefore, the shorelines had less than one year to recover from the impacts of the storm prior to the 1999 survey. While shoreline changes between 1993 and 1999 were rather high, the preceding time period, 1978 to 1993, which had relatively low storm activity, also experienced high rates shoreline erosion over the area from Pine Knoll Shores to West Emerald Isle. The accretion experienced by Atlantic Beach during this period was due to the 1986 disposal operation from Brandt Island.

			Table C-1						
		Relative Storm Intensity for Storms Passing Near Morehead City							
Date of Storm	Name	Type of Storm	Dist from MHC (d) (miles)	Direction frm MHC	Wind Speed V (kts)	Factor (f) (1)	Storm intensity (V^2/d)* P	Sum Storm Intensity for time period	Average SIF for period
6/22/1886	NA	Trop Storm	180	NW	35	1.5	10.2		
7/02/1886	NA	Trop Storm	120	NW	35	1.5	15.3		
7/20/1886	NA	Hurr-1	80	S	70	2.0	122.5		
8/24/1886	NA	Hurr-2	155	S	85	2.0	93.2		
8/21/1887	NA	Hurr-2	65	S	90	2.0	249.2		
8/24/1887	NA	Hurr-3	135	S	105	2.0	163.3		
10/31/1887	NA	Trop Storm	100	S	40	2.0	32.0		
9/10/1888	NA	Trop Storm	145	NW	35	1.5	12.7		
9/25/1888	NA	Trop Storm	100	S	50	2.0	50.0		
10/11/1888	NA	Trop Storm	45	N	60	2.0	160.0		
11/25/1888	NA	Hurr-2	155	SE	85	1.0	46.6		
6/19/1889	NA	Trop Storm	50	S	45	2.0	81.0		
9/24/1889	NA	Trop Storm	140	N	45	1.5	21.7		
10/6/1889	NA	Trop Storm	75	S	50	2.0	66.7		
9/7/1891	NA	Hurr-2	300	SE	85	1.0	24.1		
10/9/1891	NA	Trop Storm	120	S	45	2.0	33.8		
10/11/1891	NA	Trop Storm	75	S	35	2.0	32.7		
10/12/1891	NA	Hurr-2	150	SE	85	1.0	48.2		
6/16/1892	NA	Trop Storm	90	S	40	2.0	35.6		
6/17/1893	NA	Trop Storm	60	N	50	1.5	62.5		
8/21/1893	NA	Hurr-3	215	SE	105	1.0	51.3		
8/23/1893	NA	Hurr-2	175	SE	85	1.0	41.3		
8/29/1893	NA	Hurr-1	220	NW	75	1.5	38.4		
10/13/1893	NA	Hurr-1	160	NW	80	1.5	60.0		
10/4/1893	NA	Trop Storm	60	N	35	1.5	30.6		
23-Oct-83	NA	Trop Storm	50	S	45	2.0	81.0		
11/8/1893	NA	Trop Storm	60	S	50	2.0	83.3		
9/29/1894	NA	Hurr-1	50	N	50	2.0	100.0		
10/10/1894	NA	Hurr-1	70	N	65	1.5	90.5		
9/7/1896	NA	Hurr-3	370	SE	105	1.0	29.8		
9/23/1896	NA	Hurr-2	305	SE	85	1.0	23.7		
9/29/1896	NA	Hurr-1	200	NW	75	1.5	42.2		
10/11/1896	NA	Hurr-2	140	S	85	2.0	103.2		
9/23/1897	NA	Trop Storm	30	N	40	2.0	106.7		
10/20/1897	NA	Trop Storm	30	S	40	2.0	106.7		
10/26/1897	NA	Trop Storm	75	NE	45	1.0	27.0		
10/1/1898	NA	Hurr-2	350	S	95	2.0	51.6		
10/12/1898	NA	Trop Storm	225	S	50	2.0	22.2		
8/18/1899	NA	Hurr-2	60	S	90	2.0	270.0		
10/6/1899	NA	Trop Storm	60	S	40	2.0	53.3		
10/31/1899	NA	Hurr-1	100	SW	70	2.0	98.0		
12-Jul-01	NA	Trop Storm	5	S	40	2.0	640.0		
19-Sep-01	NA	Extratrop	40	S	35	2.0	61.3		
16-Jun-02	NA	Extratrop	175	NW	25	1.5	5.4		
15-Sep-04	NA	Hurr-1	125	NW	65	1.5	50.7		
05-Nov-04	NA	Trop Storm	50	S	35	2.0	49.0		
18-Jun-06	NA	Hurr-2	200	S	85	2.0	72.3		
07-Sep-06	NA	Hurr-3	430	SE	100	1.0	23.3		
17-Sep-06	NA	Hurr-2	105	S	110	2.0	230.5		
29-Jun-07	NA	Extratrop	20	SW	30	2.0	90.0		
29-Sep-07	NA	Trop Storm	130	S	35	2.0	18.8		
31-Jul-08	NA	Hurr-1	5	S	70	2.0	1960.0		
01-Sep-08	NA	Trop Storm	80	E	45	1.0	25.3		
23-Oct-08	NA	Trop Storm	180	S	35	2.0	13.6		
28-Sep-09	NA	Trop Storm	240	S	40	2.0	13.3		
20-Oct-10	NA	Trop Storm	30	S	55	2.0	201.7		
26-Aug-11	NA	Hurr-2	250	S	85	2.0	57.8		
15-Jun-12	NA	Trop Storm	90	N	35	1.5	20.4	**Pre-Project Period**	
06-Oct-12	NA	Hurr-1	135	SE	80	1.0	47.4	**1886 to 1936**	**Ave**
23-Nov-12	NA	Hurr-1	210	SE	65	1.0	20.1	**8783.8**	**175.7**
03-Sep-13	NA	Hurr-1	15	NE	70	2.0	653.3		
11-Oct-13	NA	Trop Dep	70	NW	15	1.5	4.8		
03-Aug-15	NA	Trop Dep	195	NW	30	1.5	6.9		
19-Jul-16	NA	Hurr-2	200	SE	95	1.0	45.1		
06-Sep-16	NA	Trop Storm	130	SW	35	2.0	18.8		
24-Aug-18	NA	Trop Storm	15	SW	50	2.0	333.3		

Table C-1 (Continued) Relative Storm Intensity for Storms Passing Near Morehead City									
Date of Storm	Name	Type of Storm	Dist from MHC (d) (miles)	Direction frm MHC	Wind Speed V (kts)	Factor (f) (1)	Storm intensity (V^2/d)* P	Sum Storm Intensity for time period	Average SIF for period
22-Sep-20	NA	Hurr-1	90	SW	70	2.0	108.9		
16-Oct-21	NA	Trop Storm	200	S	40	2.0	16.0		
28-Sep-23	NA	Hurr-3	290	SE	100	1.0	34.5		
23-Oct-23	NA	Extratrop	115	E	60	1.0	31.3		
26-Aug-24	NA	Hurr-3	70	S	110	2.0	345.7		
17-Sep-24	NA	Trop Storm	50	S	40	2.0	64.0		
30-Sep-24	NA	Extratrop	100	NW	35	1.5	18.4		
02-Dec-25	NA	Trop Storm	20	N	20	2.0	40.0		
19-Sep-28	NA	Trop Storm	60	NW	40	1.5	40.0		
13-Sep-30	NA	Hurr-1	80	SE	70	1.0	61.3		
16-Sep-32	NA	Extratrop	50	S	35	2.0	49.0		
23-Aug-33	NA	Hurr-2	100	NE	85	1.0	72.3		
08-Sep-34	NA	Extratrop	60	S	75	2.0	187.5	**Last 21 years of pre-project**	
21-Jul-34	NA	Trop Storm	90	S	40	2.0	35.6	**Period**	
06-Sep-35	NA	Hurr-1	100	N	65	1.5	63.4	**1915 to 1936**	**Ave**
18-Sep-36	NA	Hurr-2	100	SE	90	1.0	81.0	**1652.9**	**82.6**
31-Jul-37	NA	Trop Storm	40	S	60	2.0	180.0		
06-Aug-37	NA	Trop Storm	110	SE	50	1.0	22.7		
24-Oct-38	NA	Extratrop	30	N	35	2.0	81.7		
01-Sep-40	NA	Hurr-1	110	SE	70	1.0	44.5		
12-Oct-42	NA	Trop Dep	50	NW	25	1.5	18.8		
02-Aug-44	NA	Trop Storm	100	SW	60	2.0	72.0		
14-Sep-44	NA	Hurr-2	60	S	90	2.0	270.0		
20-Oct-44	NA	Trop Storm	110	NW	35	1.5	16.7	**Shoreline Change Period**	
26-Jun-45	NA	Trop Storm	30	N	50	2.0	166.7	**1933 to 1946**	**Ave**
06-Jul-46	NA	Trop Storm	50	N	45	1.5	60.8	**1373.5**	**72.3**
24-Aug-49	NA	Hurr-2	60	S	95	2.0	300.8		
21-May-51	Able	Hurr-3	110	SE	100	1.0	90.9		
04-Oct-51	How	Hurr-2	100	SE	95	1.0	90.3		
14-Aug-53	Barbara	Hurr-2	30	N	90	2.0	540.0	**Ebb Tide Delta Change Period**	
28-Sep-53	Florence	Extratrop	70	N	35	1.5	26.3	**1936 to 1952**	**Ave**
31-Aug-54	Carol	Hurr-2	50	S	85	2.0	289.0	**1415.8**	**88.5**
11-Sep-54	Edna	Hurr-3	80	SE	105	1.0	137.8		
15-Oct-54	Hazel	Hurr-3	170	SW	110	2.0	142.4		
12-Aug-55	Connie	Hurr-1	30	N	80	2.0	426.7		
17-Aug-55	Diane	Hurr-1	80	SW	75	2.0	140.6		
19-Sep-55	Ione	Hurr-3	10	S	100	2.0	2000.0		
27-Sep-56	Flossy	Extratrop Dep	50	N	30	1.5	27.0		
28-Sep-58	Helene	Hurr-3	50	S	115	2.0	529.0	[redacted]	
10-Jul-59	Cindy	Trop Dep	100	NW	30	1.5	13.5		
12-Sep-60	Donna	Hurr-2	20	N	95	2.0	902.5		
30-Jul-60	Brenda	Trop Storm	70	W	50	2.0	71.4		
14-Sep-61	NA	Trop Storm	70	N	35	1.5	26.3		
28-Aug-62	Alma	Hurr-1	40	S	65	2.0	211.3		
20-Oct-63	Ginny	Hurr-1	90	SE	75	1.0	62.5		
08-Jun-64	NA	Trop Storm	70	S	40	2.0	45.7		
01-Sep-64	Cleo	Trop Dep	110	N	35	1.5	16.7		
13-Sep-64	Dora	Trop Storm	70	N	45	1.5	43.4		
16-Oct-64	Isbell	Hurr-1	20	S	65	2.0	422.5		
16-Jun-65	NA	Extratrop Dep	100	N	30	1.5	13.5		
11-Jun-66	Alma	Hurr-1	70	S	70	2.0	140.0		
17-Sep-67	Doria	Trop Storm	20	E	35	2.0	122.5		
13-Jun-68	Abby	Trop Dep	20	SE	25	2.0	62.5		
12-Aug-68	Dolly	Trop Dep	100	S	30	2.0	18.0		
20-Oct-68	Gladys	Hurr-1	30	S	70	2.0	326.7		
09-Sep-69	Gerda	Hurr-2	90	S	85	2.0	160.6		
17-Aug-70	NA	Trop Dep	20	N	30	2.0	90.0		
12-Aug-71	Beth	Trop Dep	170	S	30	2.0	10.6	**Ebb Tide Delta Change Period**	
27-Aug-71	Doria	Trop Storm	10	N	55	2.0	605.0	**1960 to 1974**	**Ave**
01-Oct-71	Ginger	Hurr-1	20	E	65	2.0	422.5	**2850.7**	**203.6**
22-Jun-72	Agnes	Trop Dep	60	N	45	1.5	50.6		
29-Jun-75	Amy	Trop Storm	50	S	35	2.0	49.0		
27-Oct-75	Hallie	Trop Storm	70	S	45	2.0	57.9	**Shoreline Change Period**	
24-May-76	NA	Trop Storm	90	S	45	2.0	45.0	**1947 to 1978**	**Ave**
09-Aug-76	Belle	Hurr-2	110	E	95	1.0	82.0	**8812.8**	**275.4**
06-Sep-77	Clara	Trop Dep	40	S	25	2.0	31.3		
15-Jul-79	Bob	Trop Dep	30	NE	20	2.0	26.7		
20-Aug-81	Dennis	Trop Storm	20	S	60	2.0	360.0		
14-Sep-84	Diana	Trop Storm	50	N	50	1.5	75.0		
30-Sep-84	Isidore	Trop Storm	80	S	50	2.0	62.5		

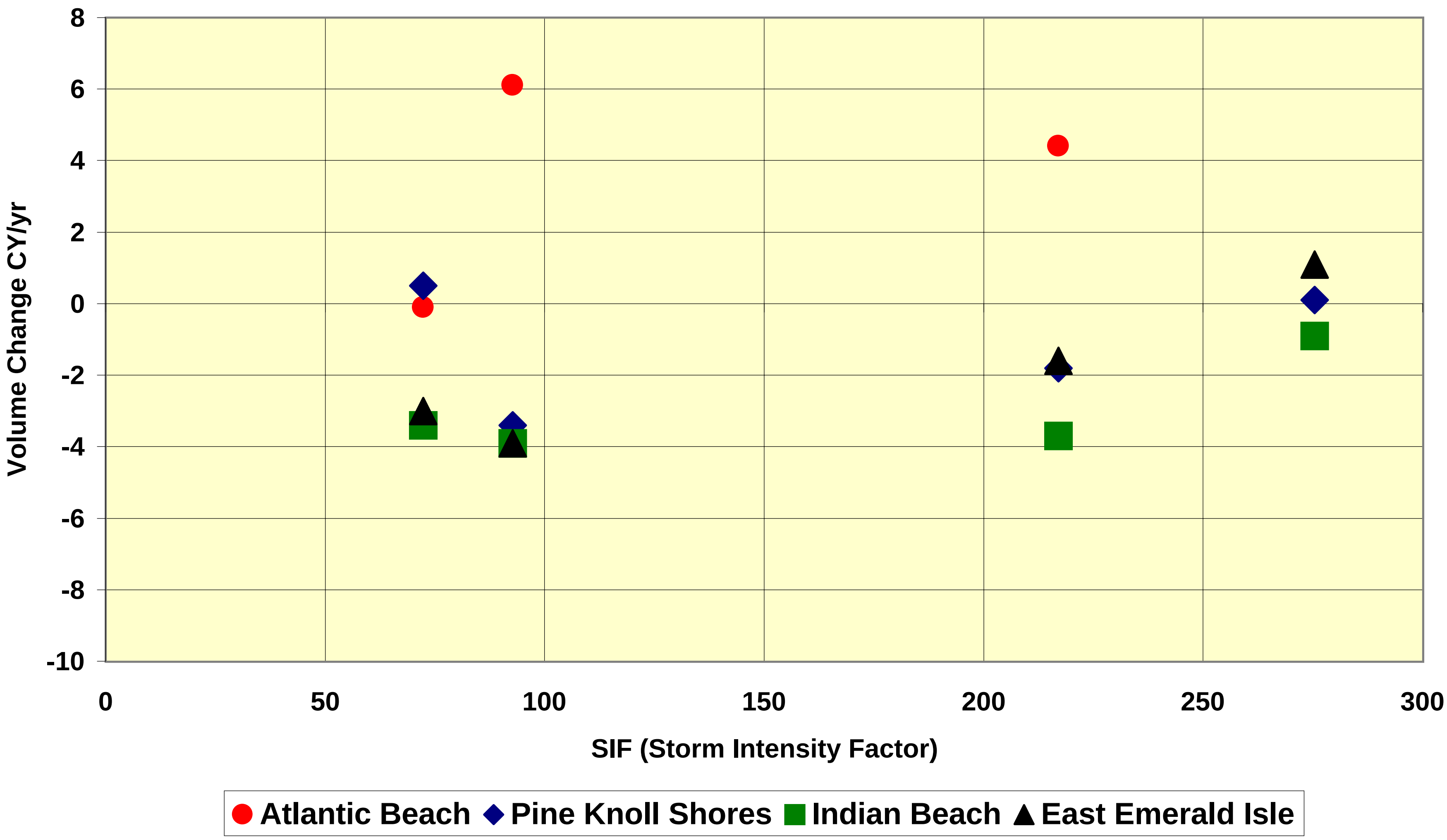
Table C-1 (Continued) Relative Storm Intensity for Storms Passing Near Morehead City									
Date of Storm	Name	Type of Storm	Dist from MHC (d) (miles)	Direction frm MHC	Wind Speed V (kts)	Factor (f) (1)	Storm intensity (V^2/d)* P	Sum Storm Intensity for time period	Average SIF for period
10-Aug-85	Claudette	Subtrop Dep	115	S	30	2.0	15.7		
27-Sep-85	Gloria	Hurr-2	90	E	90	1.0	90.0		
14-Oct-85	Isabel	Trop Dep	80	S	25	2.0	15.6		
23-Nov-85	Kate	Trop Storm	30	S	40	2.0	106.7		
07-Jun-86	Andrew	Trop Storm	90	S	45	2.0	45.0		
17-Aug-86	Charley	Hurr-1	20	E	65	2.0	422.5	**Ebb Tide Delta Change Period**	
06-Aug-88	Alberto	Trop Dep	100	E	25	1.0	6.3	**1974 to 1988**	**Ave**
22-Sep-89	Hugo	Hurr-4	220	SW	120	2.0	130.9	**1491.0**	**106.5**
03-Jul-91	Ana	Trop Dep	90	S	30	2.0	20.0		
19-Aug-91	Bob	Hurr-3	80	E	100	1.0	125.0	**Shoreline Change Period**	
25-Sep-92	Danielle	Trop Storm	110	E	45	1.0	18.4	**1978 to 1993**	**Ave**
31-Aug-93	Emily	Hurr-3	85	E	100	1.0	117.6	**1668.1**	**92.7**
18-Nov-94	Gordon	Hurr-1	90	SW	70	2.0	108.9		
06-Jun-95	Allison	Extratrop Storm	80	N	40	1.5	30.0	**Shoreline Change Period**	
17-Aug-95	Felix	Hurr-1	220	E	65	1.0	19.2	**1993 to 1998**	**Ave**
20-Jun-96	Arthur	Trop Storm	20	S	35	2.0	122.5	**1085.2**	**217.0**
13-Jul-96	Bertha	Hurr-1	55	SW	65	2.0	153.6		
06-Sep-96	Fran	Hurr-3	100	SW	100	2.0	200.0	**Shoreline Change Period**	
08-Oct-96	Josephine	Extratrop Storm	40	N	45	1.5	75.9	**1978 to 1999**	**Ave**
27-Aug-98	Bonnie	Hurr-1	30	NW	75	2.0	375.0	**2754.2**	**137.7**
04-Sep-99	Dennis	Trop Storm							
16-Sep-99	Floyd	Hurr							
17-Oct-99	Irene	Hurr							
				Total All years =			**21284.7**		
				Average All Years =			**188.4**		
		Average for with-project conditions (1936 - 1998) =					**198.4**		

Figure C-1 Storm Intensity Factors-1886 to 1998



NC Storms
storm intensity.xls
SIF vs time

Figure C-2 SIF vs Shoreline Change Rates for Atlantic Beach, Pine Knoll Shores, Indian Beach, and East Emerald Isle



storm intensity.xls
fig 7.39